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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

JANUARY 1955

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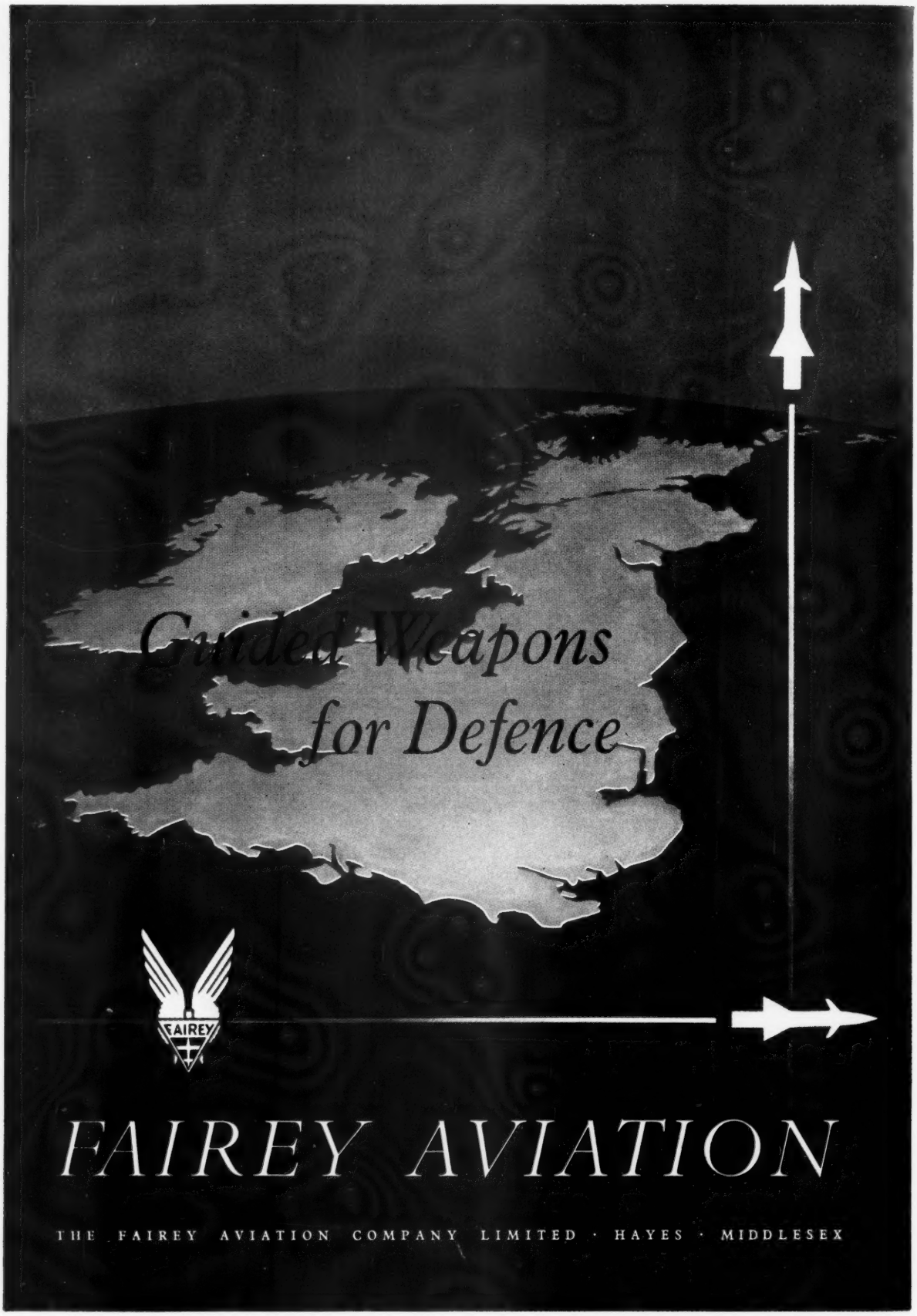
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ADDITIONS TO THE LIBRARY. REPORTS.

All communications for publication in, and advertisements for, the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., A.F.I.A.S., A.F.R.Ae.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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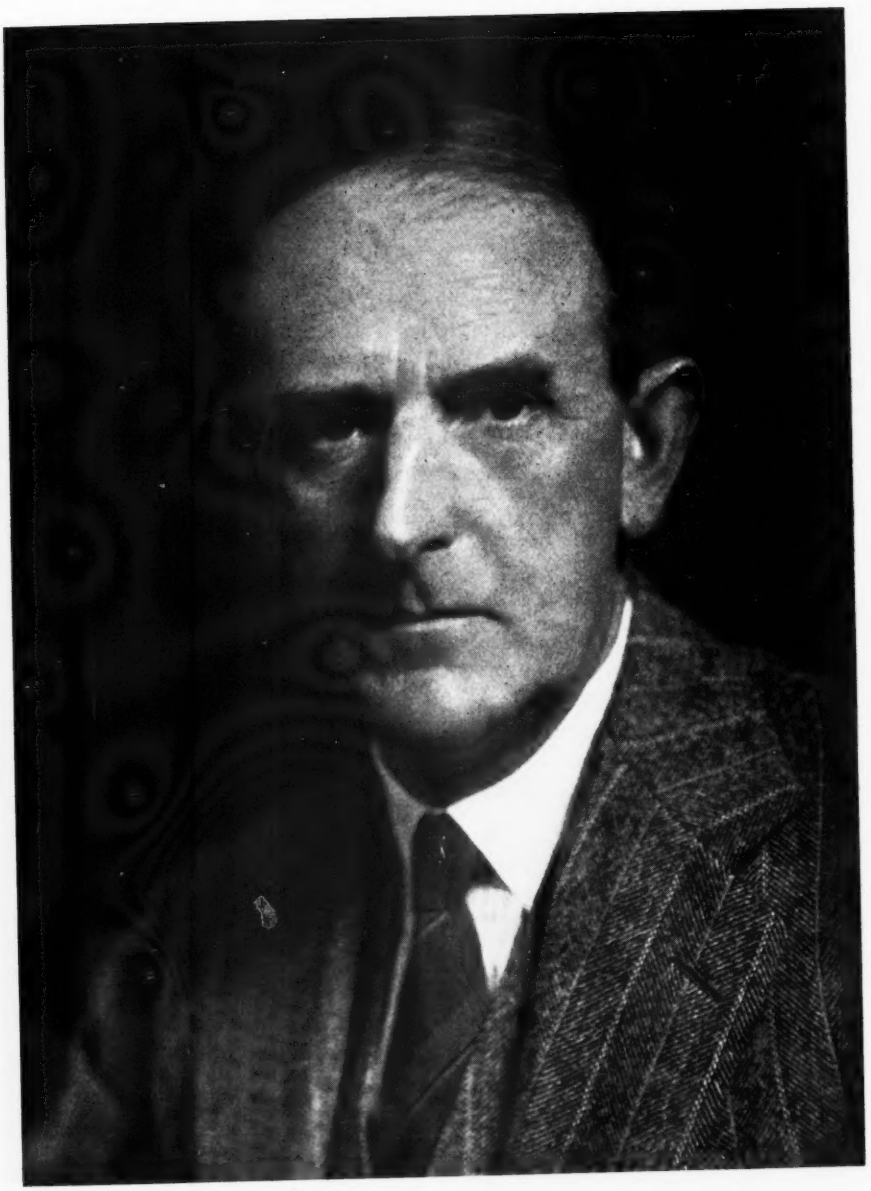


Sir Sydney Camm, C.B.E., F.R.Ae.S.

President 1954 - 1955

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 59 JANUARY 1955 NUMBER 529

From the President

ALTHOUGH I have been a member of Council for very many years, and should by now be familiar with the work of the Society, since I have become President I have been much more aware of the tremendous importance of the Society to aviation, and also of the valuable work of the Branches. We who live near London are apt to overlook the interests of our members much farther afield, and of course the Divisions overseas.

In this connection, the past year has been very important, because in May our Secretary, accompanied by Mrs. Ballantyne, was able to visit Canada and attend the inaugural meeting of the Canadian Aeronautical Institute in Montreal. On this occasion he also visited Toronto and New York. In July the Secretary embarked on a more ambitious journey, and visited the Divisions in Australia, South Africa and New Zealand, and also the Singapore Branch. These visits were undoubtedly of great value, and perhaps their effects were expressed in the following quotation from a letter I received from the President of the Division in South Africa:

" It is difficult for me to express how greatly I personally appreciated this gesture on behalf of the Parent Society, but I can assure you that Dr. Ballantyne's visit has cemented the bonds which exist between our Division and the Society itself . . . he brought us a Standard which, when he presented it to me at the Extraordinary General Meeting, seemed to consolidate the intangible link which exists between our Parent Body and ourselves . . . "

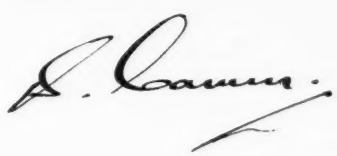
The Society's 1954 Garden Party was held at London Airport, as we felt that it would be of interest for the members to see some of the work there, as well as the newly acquired Nash Collection of Vintage Aircraft. The weather was about as bad as it could be, but nevertheless the attendance was good and the Party a success. In the past few months many meetings have been held to discuss the future of the Collection, under the Chairmanship of Mr. Peter Masefield, and a committee has been set up to determine the lines on which a National Collection or Museum could be formed.

During this year the Council has been concerned with the arrangements for the Fifth Anglo-American Aeronautical Conference to be held in Los Angeles next June, and I sincerely hope that our representation will be a strong one, as this Conference is of national importance.

1954 was a memorable year as it was the occasion of the Tenth British Commonwealth and Empire Lecture, which was given by His Royal Highness, the Duke of Edinburgh in Church House, Westminster. At the conclusion of the Lecture, as members will know, His Royal Highness was presented with the Diploma of Honorary Fellowship.

Previous Presidents have referred to the Secretary and Staff of the Society, but I feel some difficulty in putting into words how much I have benefited from their assistance, and how fortunate we are to have such a keen and enthusiastic Staff.

I look forward to the steady expansion of the Society's activities, and to all our members at home and overseas I send greetings and best wishes for the New Year.



NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Nominations for Fellowship of the Society

The attention of Members is drawn to the following extract from the Society's By-Laws:—

"Fellows shall comprise every person who on the 30th day of January 1950 was on the Register as a Fellow of the Society; and every person thereafter awarded the honour of Fellowship.

"Elections to Fellowship will be made annually by the Council and will be announced at the Annual General Meeting of the Society. Nominations will be initiated by the members of the Council or by any four Fellows of the Society. It is the duty of the Council to see that the honour is awarded only to persons who have attained a considerable degree of technical eminence in the profession of aeronautics."

From this, it will be seen that any four Fellows may nominate a suitable candidate for Fellowship. Nominations for 1955 must be received by the Secretary before 31st January 1955.

Graduates' and Students' Section—Annual General Meeting

The Annual General Meeting of the Section will be held in the Offices of the Society, 4 Hamilton Place, W.1, on Wednesday 9th March 1955, at 7.0 p.m. Light refreshments will be served from 6.30 p.m. to 7.0 p.m.

The meeting will be followed by a film show, admission to which will be by ticket only.

Agenda

1. To consider and approve the Minutes of the previous Annual General Meeting.
2. To consider any business arising from these Minutes.
3. To receive the report of the Committee on the activities of the Committee and the Section during the past year.
4. To make recommendations to Council on the names of the representatives of the Section to serve on the Committee for the year 1955-56.
5. To receive the rules for the administration of the Section.
6. To discuss the future activities of the Section.
7. To consider any other matters connected with the affairs of the Section.

Nominations for the Section representatives on the Committee should be sent to the Hon. Secretary before the 7th March, or may be handed in at the meeting. They must be signed by the candidate, proposer and seconder, who must all be Graduates or Students. The number of vacancies to be filled is nine and, if the nominations exceed this number, a ballot will be held at the meeting.

The successful candidates' names will be subject to confirmation by Council.

Members are reminded that it is desirable for the Committee to be representative of as many firms and Colleges as possible.

Alan E. Brock,
Hon. Secretary.

77 Broughton Road
Thornton Heath, Surrey

Associate Fellowship Examination

Entries for the next Associate Fellowship Examination should be received from candidates in the British Isles by 28th February. The list of candidates taking the examination abroad is now closed.

Captain J. L. Pritchard

Captain J. Laurence Pritchard, C.B.E., *Honorary Fellow*, Hon.F.I.A.S., member of Council, sailed on 10th January 1955 for the United States where he is to give a series of lectures at more than 20 Universities and sections of the Institute of the Aeronautical Sciences.

He will lecture on the History of the Society and its relationship with American individuals and organisations during the past 80 years, on the Wright Brothers from the British point of view, and on the history of British Aviation between 1804 and 1954.

Captain Pritchard's schedule includes the celebrations of the Centenary of the Polytechnic Institute of Brooklyn on 20th January, the Honors Night Dinner of the Institute of the Aeronautical Sciences and a historical Meeting of the I.A.S. during the Institute's Annual Meeting in New York on 26th January. Among the places he will lecture are the Universities of Johns Hopkins, Princeton, Cornell, Michigan, Purdue, Illinois, Colorado, California, the Massachusetts Institute of Technology, the Polytechnic Institute of Brooklyn, the Californian Institute of Technology and the State Colleges of Iowa and Mississippi.

Captain Pritchard is also expected to give the first lecture at the founding in Vancouver of a Branch of the Canadian Aeronautical Institute and, in addition, to study correspondence of the Wright Brothers with members of the Royal Aeronautical Society at the Library of Congress, Washington.

He expects to be back in England about the middle of April.

News of Members

R. Boorman (*Fellow*), formerly Deputy Chief Engineer, has been appointed Chief Structural Engineer at Short Bros. and Harland Ltd.

G. M. Cutler (*Associate Fellow*) has taken up an appointment as Chief Technical Engineering (Medium Cars) with Humber Limited, Coventry.

V. F. Gardener (*Associate Fellow*) has taken up employment with A. V. Roe (Canada) Ltd. at Malton, Ontario.

R. Goldby (*Associate Fellow*) has been appointed Contracts Manager to Dowty Fuel Systems Ltd.

Sqdn. Ldr. T. H. Hanson (*Associate Fellow*) has taken up a special appointment in the Directorate of Air Engineering at the Air Ministry, on his retirement from the R.A.F.

C. D. Hatton (*Associate Fellow*) has been appointed Assistant Chief Engineer (Aircraft) at Short Bros. and Harland Ltd.

Wing Commander E. A. Harrop (*Associate Fellow*) has been appointed to the Logistics Department, R.A.F. Element, Allied Air Forces Central Europe.

Group Captain R. C. Hockey (*Associate*) has been appointed Personal Executive to the Managing Director of Blackburn and General Aircraft Ltd.

Sqdn. Ldr. K. C. Krishnan (*Associate Fellow*) has been posted to New Delhi as Deputy Director of Development and Production (Air).

K. L. C. Legg (*Associate Fellow*), formerly Assistant Designer, Structures, has been appointed Structural Development Engineer at Short Bros. and Harland Ltd.

William Morse (*Associate Fellow*) has resigned from A. V. Roe (Canada) Ltd. to become Editor of the new Maclean-Hunter publication, "Design Engineering."

J. G. M. Pardoe (*Associate Fellow*) has been appointed Deputy Chief Technical Officer of the Air Registration Board.

Diary

18th **January**
SECTION LECTURE.—Manufacture of Integral Structures. Dr. E. G. West. 4 Hamilton Place, W.1. 7 p.m.

25th January
GRADUATES' AND STUDENTS' SECTION.—Test Flying a V-Bomber. Sqdn.-Ldr. H. G. Hazelden and R. H. Williams. 4 Hamilton Place, W.1. 7.30 p.m.

27th January
SECTION LECTURE.—Dynamic Problems of Interplanetary Flight. D. F. Lawden. 4 Hamilton Place, W.1. 7 p.m.

8th **February**
SECTION LECTURE.—Some Trends in the Development of Aircraft Electrical and Starting Systems. R. H. Woodall. 4 Hamilton Place, W.1. 7 p.m.

10th February
MAIN LECTURE AT ISLE OF WIGHT BRANCH.—Problems and Aspects of Rocket Propulsion for Aircraft. Professor A. D. Baxter. Saunders-Roe Club House, Church Path, E. Cowes. 7 p.m.

15th February
GRADUATES' AND STUDENTS' SECTION.—Discussion: Is Post-graduate Study Abroad Worthwhile? Chairman, Sir Arnold Hall. 4 Hamilton Place, W.1. 7.30 p.m.

17th February
SECTION LECTURE.—Problems Associated with Stress Concentration. H. L. Cox. 4 Hamilton Place, W.1. 7 p.m.

19th February
GRADUATES' AND STUDENTS' SECTION.—Visit to the Guinness Brewery at Park Royal, London. 2.15 p.m.

1st **March**
SECTION LECTURE.—The Scientific Approach and Research in Aircraft Production. Professor J. V. Connolly. 4 Hamilton Place, W.1. 7 p.m.

BRANCHES

11th January
Boscombe Down.—The Domain of the Helicopter. R. Hafner. Main Dining Hall, Airmen's Mess, A. and A.E.E., Boscombe Down. 5.30 p.m.

12th January
Manchester.—Hydraulics. E. J. Nicholl. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.
Southampton.—Annual General Meeting, followed by Film Show. Institute of Education, University of Southampton. 7 p.m.
Weybridge.—The Mechanical Test Department: Its Organisation and Function. J. H. Cork, W. Astley, G. F. M. Hawkins. Vickers-Armstrongs Ltd., Weybridge. 6 p.m.

13th January
Glasgow.—Film Evening. Royal Technical College, Glasgow. 7.30 p.m.

14th January
Birmingham.—Visit to Wolverhampton.

17th January
Halton.—Compound Engines. E. E. Chatterton. Branch Hut, R.A.F., Halton. 6.45 p.m.

19th January
Coventry.—Dr. A. M. Ballantyne will give an illustrated talk on his visits to the Overseas Divisions of the Society. Wine Lodge, Coventry. 7.30 p.m.

24th January
Henlow.—The Large Transport Helicopter — Its Design Problems. Dr. G. S. Hislop. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

25th January
Belfast.—The Helicopter—Has it a Future? F. H. Robertson. Kerr Room, Kensington Hotel, Belfast. 7 p.m.

26th January
Preston.—The Domain of the Helicopter. R. Hafner. Queen's Hotel, Lytham. 7.30 p.m.
Weybridge.—Fuels and Lubricants for Aviation. Dr. C. B. Davies. Vickers-Armstrongs Ltd., Weybridge. 6 p.m.

27th January
Yeovil.—History of Helicopter Patents. L. H. Hayward. Park School, Park Road (off Princes St.), Yeovil. 7.30 p.m.

31st January
Halton.—Junior Members' Night. History of the Helicopter and other Films. Branch Hut, R.A.F., Halton. 6.45 p.m.

2nd **February**
Brough.—Air Accidents. Air Commodore Sir Vernon Brown, C.B., O.B.E. Lecture Hall, Yorkshire Electricity Board, Ferensway, Hull. 7.30 p.m.
Chester.—Global Winds and Weather. C. S. Durst, O.B.E. The Grosvenor Hotel, Chester. 7.30 p.m.
Luton.—Controls and Stability. J. C. Wimpenny. George Hotel, Luton. 7.30 p.m.
Southampton.—The Light-weight Jet Engine. Dr. S. G. Hooker, O.B.E. Institute of Education, University of Southampton. 7 p.m.

3rd February
Cheltenham.—Area Lecture: Coventry, Birmingham, Gloucester and Cheltenham Branches. Comparisons of some Aircraft Propulsion Systems. Professor A. D. Baxter. St. Mary's College, Cheltenham. 7.30 p.m. (Coach from Coventry leaves Baginton 5.20 p.m., going *via* Whitley and Parkside.)

7th February
Belfast.—Rocket Motors. D. G. Kennedy. Reception Room, Kensington Hotel, Belfast. 7 p.m.
Halton.—Films: Oil, The Unseen Traveller, As Old as the Hills, 10,000 ft. deep. Branch Hut, R.A.F., Halton. 6.45 p.m.
Henlow.—Annual General Meeting. Building No. 62, R.A.F. Technical College, Henlow. 6.45 p.m.

8th February
Boscombe Down.—Film Evening. Main Dining Hall, Airmen's Mess, A. and A.E.E., Boscombe Down. 5.30 p.m.

9th February
Weybridge.—Brains Trust. Vickers-Armstrongs, Weybridge. 6 p.m.

10th February
Isle of Wight.—Main Lecture: Problems and Aspects of Rocket Propulsion for Aircraft. Professor A. D. Baxter. Saunders-Roe Club House, Church Path, E. Cowes. 7 p.m.

11th February
Birmingham.—The Development of Re-Heat. J. L. Edwards. Birmingham Chamber of Commerce, New Street, Birmingham. 7.30 p.m.
Glasgow.—Operation and Servicing of Jet Engines. J. R. Nutter. Royal Technical College, Glasgow. 7.30 p.m.

14th February
Halton.—Electronic Equipment. Branch Hut, R.A.F., Halton. 6.45 p.m.

16th February
Manchester.—The Scientific Approach to Production Problems. Professor J. V. Connolly. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

17th February
Yeovil.—Fatigue. Dr. P. B. Walker. Park School, Park Road (off Princes St.), Yeovil. 7.30 p.m.

21st February
Halton.—Branch Night. Aircraft Operations in the Arctic. Major Webb, U.S.A.A.F. Branch Hut, R.A.F., Halton. 6.45 p.m.
Henlow.—Aircraft Production. Professor J. V. Connolly. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

22nd February
Belfast.—Trends of Engine Development. Dr. S. G. Hooker. Kerr Room, Kensington Hotel, Belfast. 7 p.m.

23rd February
Preston.—Lecture. Harris Institute, Preston. 7.30 p.m.
Southampton.—Branch Prize Papers. Institute of Education, University of Southampton. 7 p.m.
Weybridge.—R. K. Pierson Memorial Lecture. W. E. W. Petter, C.B.E. Vickers-Armstrongs Ltd., Weybridge. 6 p.m.

Journal Binding

Permanent Binding

The new prices for permanent binding of Journals are:
1954 Volume (including packing and postage) 18s. 6d.
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Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Self-Binder Cases

Self-Binder cases of the "Easibind" type to hold 12 Journals (cost 11s. 6d. each) are available from the offices of the Society.

NEWS OF MEMBERS—*Continued*

R. Parker (*Graduate*) has been appointed a Senior Scientific Officer in the Ministry of Supply, Aircraft Research and Development Research Branch.

Professor Maurice Roy (*Fellow*), Director of O.N.E.R.A., has been made a "Commandeur" in the Order of "La Légion d'Honneur" for his services to aviation.

F. H. Robertson (*Associate Fellow*) has been appointed Chief Project Designer at Short Bros. and Harland Ltd.

Wing Commander C. F. Smart (*Associate Fellow*), R.A.F., has taken up a post with the Ministry of Supply. He was formerly at the Aeroplane and Armament Experimental Establishment.

R. P. Tanner (*Associate Fellow*) has been appointed development engineer to Siebe, Gorman & Co. Ltd.

C. K. Turner-Hughes (*Associate Fellow*) has been appointed commercial manager of The Plessey Co. Ltd.'s aircraft electrical division.

P. Whitford (*Associate*) has recently been appointed Airport Manager of Prestwick Airport.

H. M. Yardley (*Associate Fellow*) is now Resident Technical Officer at English Electric Co. Ltd., at Warton.

F. P. Youens (*Associate Fellow*), formerly Chief Aerodynamicist, has been appointed Advance Projects Engineer at Short Bros. and Harland Ltd.

Annual Subscriptions

Members are reminded that their annual subscriptions became due on 1st January 1955. The rates are:—

	Home			Abroad		
	£	s.	d.	£	s.	d.
Fellows	5	5	0	4	4	0
Associate Fellows	4	4	0	3	3	0
*Associates	3	3	0	3	3	0
Graduates (aged under 26)	2	2	0	2	2	0
Graduates (aged 26 and over)	2	12	6	2	12	6
Students (aged under 21)	1	1	0	1	1	0
Students (aged 21 and over)	1	11	6	1	11	6
Companions	3	3	0	3	3	0
Founder Members	2	2	0	2	2	0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

John Atkinson (*from Graduate*)
John Crampton (*from Associate*)
Clifford Ditchfield (*from Graduate*)
William George Lawrence Dorkings
William Branston Houston
John Edward Howland (*from Graduate*)
Cyril Gwynne Hughes (*from Graduate*)
Duncan Alexander MacLulich
John Cecil Martin (*from Graduate*)
John Brian Maw (*from Graduate*)
Donald Eaton Murray
Andrew Colin Nicholls (*from Graduate*)
Joseph Kenneth Royle
Johannes Ruys
Kenneth James Sewell (*from Associate*)
Alexander Uydens (*from Graduate*)
Jack Hubert Vaughan
Raymond Allan Wallis
William Francis Wiles (*from Graduate*)
Malcolm Clow Wilson (*from Graduate*)
George William Woods (*from Graduate*)

Associates

Reginald Robert Bailey
John Carter Clayden
Alan John Coe
Qona Crawshaw
Edward Bernard Goldsmith
Albert William Grattidge (*from Student*)
Richard Mascall
Maurice Frederick Mason
John Marler Sloper (*from Graduate*)
Basil Scott Wodhams (*from Student*)

Graduates

William Kulasingam Aiyadurai
Beverley George Beard
Arthur Edwin Callaway
Ronald Anderson Gellatly (*from Student*)
Arthur Graham Hopper
Kavseri Ramanathan Narayanaswamy
Rex William Penney
Albert Charles Pruden (*from Student*)
Edward Frederick Simmonds (*from Student*)
Ronald George Wade
John Edwin Wheeler
Michael Woolley

Students

William Richard Woods Ballard
John Gordon Carter
Robin Chambers
Brian Ronald Leonard Easton
Robert Eddy
Gordon Hugh Kerr Goold
William Bryan Lister Hallam
Michael Rodney Milton Heyes
Karl Helmich Hoie
Herbert Thomas Keith Lawton
John Ling
Colin William Valentine McCleery
Denis Charles Roberts
Neville Rolling
Alec John Sanders
Hugo Rowton Simpson
David John Sledge
Paul Smith
Michael Irwin Thom
Peter Wentworth Throsby
John Derek Watkins
Albert Geoffrey Willis
Robert Walter Louis Wyers

Companions

Norbert Abeles (*from Graduate*)
Peter Kenneth Cowan (*from Graduate*)
Donald Noel Hunter
Ramesh Behari Lal
Reginald Richard Silvester

Royal Meteorological Society

The Royal Meteorological Society is holding a discussion on "Airflow over Mountains" on 19th January 1955, at 5 p.m. in the Society's rooms at 49 Cromwell Road, South Kensington, S.W.7. The discussion will be opened by Mr. G. A. Corby of the Dunstable Meteorological Office, and members of the Royal Aeronautical Society are welcome to attend, and to take part in the general discussion.

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THE TENTH BRITISH COMMONWEALTH AND EMPIRE LECTURE

THE SOCIETY was greatly honoured by His Royal Highness the Duke of Edinburgh, K.G., K.T., on 16th December 1954 when he not only gave the Tenth British Commonwealth and Empire Lecture but was graciously pleased to accept Honorary Fellowship of the Society.

The lecture, entitled "Aviation and the Development of Remote Areas," was held in the Assembly Hall of Church House, Westminster, S.W.1, and was attended by a large and distinguished audience of some 800 people.

His Royal Highness was welcomed on his arrival at Church House, in Dean's Yard by Mr. H. Symons on behalf of the Archbishop of Canterbury and the Council of the Corporation of the Church House, and by Sir Sydney Camm, C.B.E., F.R.Ae.S., President of the Society, and the Secretary, Dr. A. M. Ballantyne, T.D., A.F.R.Ae.S., A.F.I.A.S.

Sir Sydney Camm, presiding at the lecture said:

"My Lords, Ladies and Gentlemen:

Tonight I have the exceptional honour of calling upon His Royal Highness the Duke of Edinburgh to deliver to us the Tenth British Commonwealth and Empire Lecture.

"The interest of Prince Philip in aviation is well-known, not merely at home but throughout the Commonwealth, and he has also shown a very active interest in the Aircraft Industry in this country. Those of us in the Industry who have had the pleasure of showing him our work know the force of his keen observations. His visits have certainly been a great inspiration to us.

"Members will know that the Society has been greatly favoured by the Royal Family. Her Majesty the Queen is our Patron, succeeding her illustrious father in this office. He, it may be remembered, presided at the Society's Wilbur Wright Memorial Lecture in 1920, when he was Duke of York.

"Tonight we are to hear from His Royal Highness his own impressions and views of civil aviation, and I will now ask him to deliver to us the Tenth British Commonwealth and Empire Lecture."

His Royal Highness the Duke of Edinburgh being welcomed on his arrival at Church House by Sir Sydney Camm, President of the Society.

P.A.—Reuter

Following the lecture, which was warmly and sincerely applauded, Sir Sydney spoke as follows:

"Your Royal Highness, My Lords, Ladies and Gentlemen:

"Two world wars since the birth of heavier-than-air flight have inevitably directed our thoughts more to the uses of the aeroplane for war than for peace. This lecture has demonstrated vividly other uses where development has been retarded. To some of us who are perhaps obsessed with the need for more and more speed in the supersonic range, it comes as rather a shock to realise that there is a need for an aircraft—as His Royal Highness has mentioned—in which the main requirement is that of extremely low speed, leading perhaps to the reintroduction of the biplane.

"We are indebted to you, Sir, for emphasising how much aviation has become a vital and integral part of the civilisation of the countries of the Commonwealth and Empire. I am sure we all regret that this aspect of aviation has been overshadowed, and the Duke's lecture, in making us understand and appreciate the difficulties and limitations of this branch of aviation, is of great value.

"I am sure you will all join with me in thanking His Royal Highness for this lecture."

Sir Sydney then announced:

"The Society is doubly honoured this evening, as I now have the additional pleasure of presenting the Diploma of Honorary Fellowship to His Royal Highness."

P.A.—Reuter

His Royal Highness the Duke of Edinburgh, K.G., K.T., delivering the Tenth British Commonwealth and Empire Lecture.

His Royal Highness the Duke of Edinburgh receiving the Scroll of Honorary Fellowship of the Society from Sir Sydney Camm, President.

P.A.—Reuter

Tenth British Commonwealth and Empire Lecture

Aviation and the Development of Remote Areas

by

H.R.H. THE DUKE OF EDINBURGH, K.G., K.T.

1. Introduction

It is a very great honour indeed to find myself addressing the Royal Aeronautical Society. If, as I am often told, "a little learning is a dangerous thing" then you are in for a very dangerous address. For much as I would like to say that I know nothing about aviation it would not be altogether true. My knowledge is of the picked-up rather than the learned variety. During the war I was either at the receiving end of enemy aviation or under a friendly and comforting umbrella, which counts as passive experience. I started flying as a passenger in about 1935, and in common with many others I have put up with all the frustrations and delays of airline travel, particularly getting to and from the airfields—this I put down to semi-active experience! The active part of my experience began two short years ago when I started to learn to fly.

From this you will gather that any views I express this evening must be treated with caution if nothing else.

For the purpose of this address I would like to divide aviation into three broad divisions. First, Service aviation, and I do not think I need define it any more closely than that; secondly, scheduled airline operation which can include some of the long distance passenger charter work, and in the third division, the rest, which is in fact largely made up of aviation in the outback of the great countries of the world.

I do not propose to make any further reference to Service aviation or civil airline operation, or to the development of aircraft for their use, because a great many people, far more qualified than I am, have covered those subjects in very great detail. In any case, it is my contention that there is much more to aviation than fighters, bombers and air liners. A comparison of figures may give a clearer picture.

Broadly speaking, in the United Kingdom there are 5,000 aircraft in the Air Force, 639 air liners and 1,618 others. In Canada there are 2,000 in the Air Force, 285 air liners and 2,409 others. In Australia 1,000 aircraft in the Air Force, 185 air liners and 634 others. New Zealand has 200 aircraft in the Air Force, 44 air liners and 416 others. South Africa has 300 in the Air Force, 44 in airline work and 441 others. It is the 5,500 aircraft in the last division which I would like to talk about.

Not very long ago the aircraft used in the three divisions were roughly comparable in cost and performance and some aircraft, notably the Dakota, have served in all three. In recent years, however, invention and development have tended to open up an ever-widening gap between the third division and the other two. To the Air Force and the Airline Operators, higher, faster, bigger and better may be an excellent motto, but it means nothing to the man who wants to do top-dressing or crop dusting from the air. It means that in a few years time there will be little use for the secondhand, high performance aircraft except in the role for which they were designed. It is therefore perhaps a good moment to take stock of the position in the third division of aviation and see what is going on and what is likely to happen in the future.

2. The Conception of Aviation in the Outback

During the recent tour of Australia and New Zealand and then later in Canada, I had a wonderful opportunity to hear about, and sometimes to see, the enormous variety of uses other than passenger-carrying to which aircraft have been put in those countries. It is not perhaps surprising that they have found so many uses for aircraft, considering the conditions. Australia and Canada are enormous countries by any standard and although New Zealand is not much bigger than the British Isles, the population is about 2½ million compared with roughly 50 million in these islands. The distances involved alone make aircraft the obvious choice for general transport. In this country all forms of aviation and transport are bedevilled by chancy weather, to say the least of it, while Australia, New Zealand and Canada are blessed with relatively good flying weather for most of the year. Services in Australia work to a 98 per cent. regularity. On top of that the attitude to flying in those countries is quite different, it is part of their life and not in the least restricted to the relatively few people who go abroad regularly, as it is largely in this country.

Aircraft and the men who fly them occupy quite a special place in the minds and affections of the people who live in remote districts. For instance, the pilots of the aircraft engaged in the outback services in the Northern Territory of Australia are doing by air, with all the added difficulties, what the carriers and bus

	AIR FORCE	AIR LINES	OTHERS
United Kingdom	5000	639	1618
Canada	2000	285	2409
Australia	1000	185	634
New Zealand	200	44	416
South Africa	300	44	441

Division of Commonwealth Aircraft.

Eric Strachan

drivers are doing in the rural areas of this country. The pilots are required to service their aircraft, repair minor defects, refuel, collect fares, issue invoices for passengers and freight, and do the loading and unloading. In addition, they are expected to run to a strict schedule, navigate over poorly mapped areas which they must know well, land and take off from a great variety of bush airfields under varying weather conditions. In fact, the pilots become well known to all the residents and become part of the life of the Territory, and the whole thing is accepted as being perfectly normal.

Many things are quite reasonably done by aircraft out there which would be the height of extravagance or folly in this country. In many cases, of course, aircraft are used not because it is easier, quicker or cheaper, but simply because there is no other way at all.

Distances, weather and the absence of other facilities, therefore, make aviation a vital and integral part of the civilisation of those countries and no longer an interesting novelty, or a convenience for the relatively few.

My first-hand knowledge of Africa and the Indian continent is rather more limited, but I imagine much the same applies there, or will do before very long, especially if the right kind of aircraft are forthcoming.

3. Aircraft in Agriculture

Now, for a moment, I would like to get down to cases because it is only by quoting cases that I can try and show you the extraordinary range and importance of aviation in the Commonwealth.

To take agriculture first. Aircraft are being used for crop-dusting, which is really a form of pest control, for seeding, top-dressing and for the survey of land and in forestry. That is, of course, broadly speaking because it would be almost as difficult to describe all the uses of aircraft in agriculture as to enumerate all the uses of a farm tractor.

Top-dressing is a speciality of New Zealand and the object of the exercise is to drop fertiliser on to otherwise inaccessible pasture land to improve the grass to feed sheep. It is important to remember that this is not an alternative way of doing it—it is the only way. Top-dressing is done by air or not at all. I do not think that there is any doubt about its usefulness. Let me give you some figures. On a 900 acre block in the Auckland district, with two seasons of top-dressing with four to six cwt. of phosphate and potash per acre, the capacity of the block has been increased from 1,200 to 2,300 ewes, and it is hoped to increase that to 3,000 in the next two years. Throughout New Zealand there were twelve aircraft employed on top-dressing in 1939. That figure has now risen to 162. In 1953 they distributed 140,000 tons of fertiliser over 1¼ million acres. Some people estimate that aerial top-dressing is capable of increasing meat production in New Zealand 50 per cent. in ten years, and the ultimate target is to treat 10 million acres of hill country.

To give some idea of the cost of this work, it is estimated that counting fertiliser, transport, dropping, interest on capital, etc., it works out at between 30/- to 34/- per acre, or some £3 per ton dropped. The latest development is a product consisting of a hormone and a superphosphate for the dual purpose of weed killing and fertilising.

Apart from top-dressing, aircraft are used to spread trace elements (this is done commercially in New Zealand for between 6d. and 1/- per acre), for sowing seeds, dropping fencing and other supplies, such as fodder and poison bait, and frost protection of valuable crops. In America it is estimated that aircraft used for agricultural purposes—and there are 7,000 of them, compared with 65 in Western Europe—spend 55 per cent. of their total flying time in pest and disease control, 35 per cent. in seeding and fertilising, and 10 per cent. in photographic survey for erosion, pest infestation and for planning irrigation works.

So far as aircraft for agriculture are concerned, particularly in spraying for pest and weed control, they have one important advantage in that they avoid any mechanical injury to the crop, which would be unavoidable with ground machinery.

Whatever purpose aircraft are used for there is one fundamental rule, the aircraft must be employed all the year round to make it worth while. The whole difficulty of operating aircraft for agriculture lies in finding a variety of uses which will achieve this ideal.

4. Aircraft in Pest Control

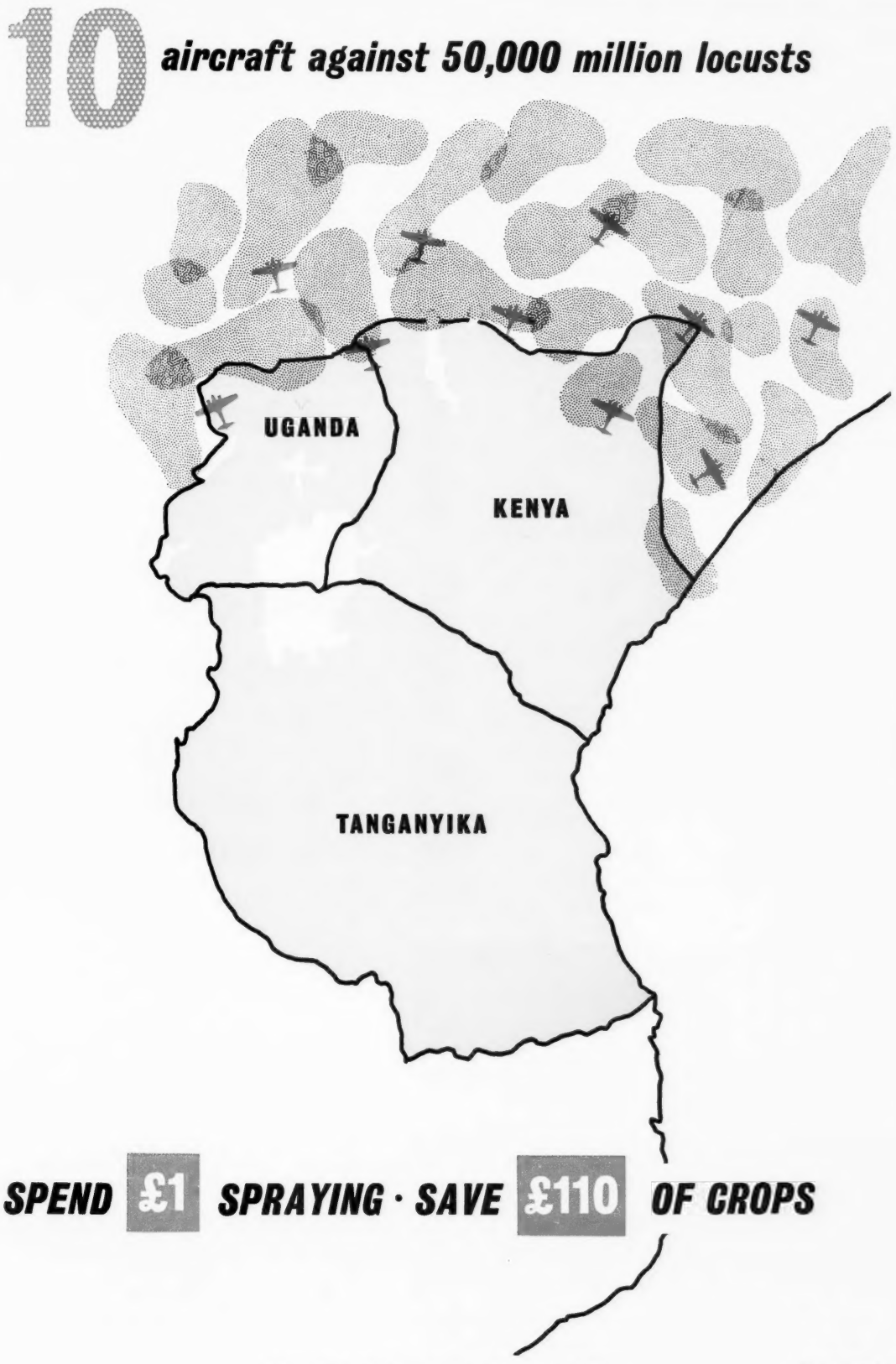
There are many sides to pest control from the air, but they are mostly alternatives to ground methods. In Africa, however, aircraft are used for locust control and in this case there is no alternative which is anything like so effective. For every pound spent on aerial spraying of locusts, crops up to the value of £110 can be saved. In 1954 a battle was fought in East Africa by 10 light aircraft, operating from a 600 mile line of bases in Kenya and Tanganyika, against an invasion by some 50 swarms with a total area of about 500 square miles and containing something like 50,000 million locusts weighing perhaps 100,000 tons. This time the locusts won, although many large swarms were attacked in flight and several were completely destroyed. During the battle it was found that 300,000 locusts can be killed by one gallon of poison sprayed from aircraft at a cost of £6 per million locusts killed.

Also in Africa, aircraft are used against what is probably the greatest obstacle to development of that continent. In Tanganyika alone, 75 per cent. of the total land is unsuited for settlement because of the tse-tse fly. They could be wiped out from the air, but at present it takes three applications and that is still rather expensive.

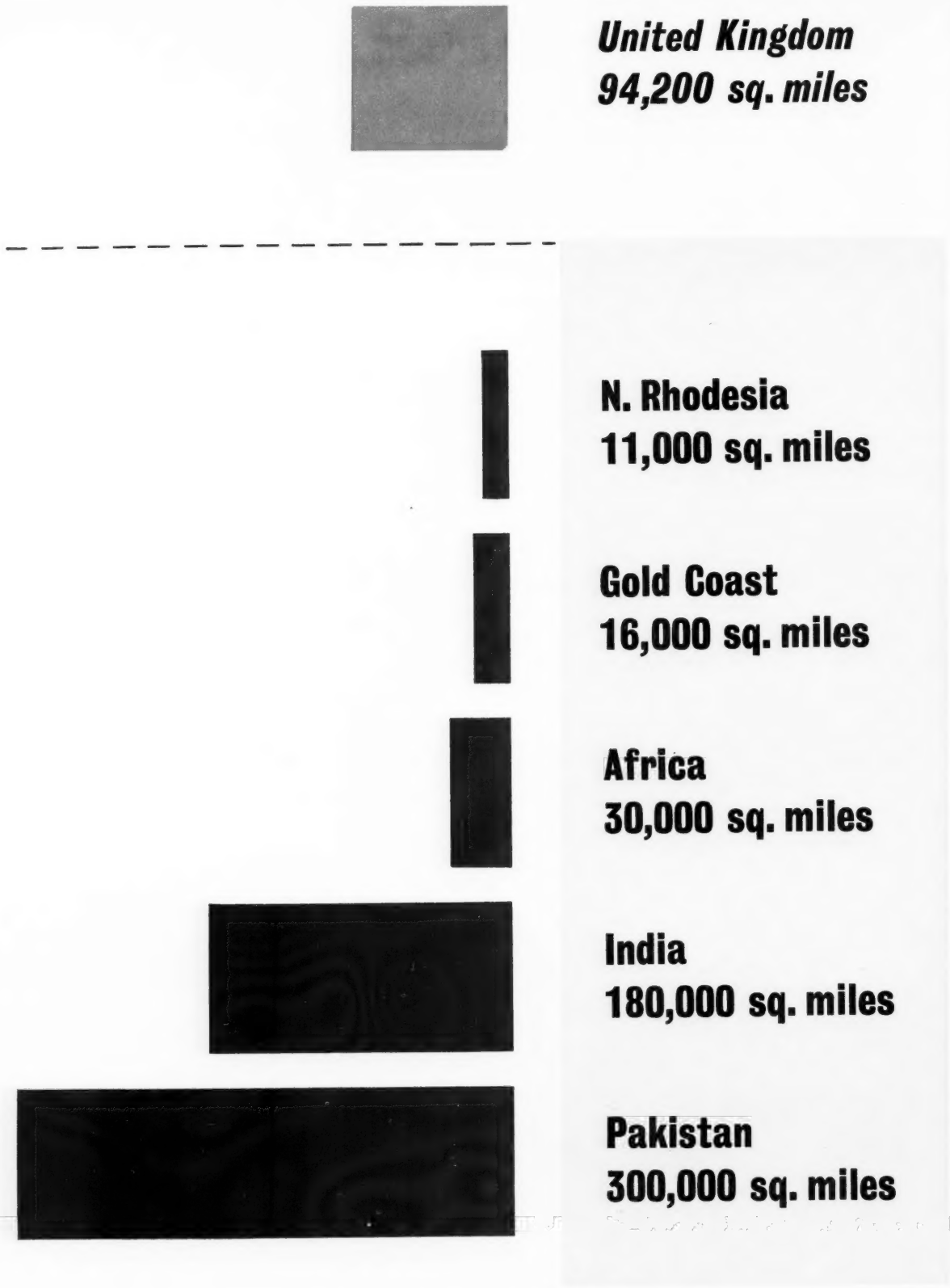
Almost every country in the Commonwealth and Empire can provide examples of the use of aircraft in pest and disease control. Forests are surveyed to find infected areas and in Canada budworm in forests have been attacked with D.D.T. with great effect.

The most important and effective way of controlling pests and diseases, if good husbandry and good sanitation prove inadequate, is by the use of poisonous chemicals. The immense development of potent new

Effects of Aerial Top-Dressing in New Zealand. *Eric Strachan*



Aircraft and Pest Control in East Africa. *Eric Strachan*



Commonwealth Areas Surveyed by Air.

Eric Strachan

chemicals in recent years has meant that only from one to 25 gallons of spray per acre are required, where 100 to 3,500 gallons would have been necessary a few years ago. In fact the low dosages at which the new chemicals are effective have been directly responsible for the increased use of aircraft for the control of pests and diseases in the past twelve years. The essential quality of aircraft which suits them for this work is their independence from the nature of the countryside, which enables them to reach standing crops, deserts for locusts, tree tops for forest pests and swamps breeding mosquitos, that would be inaccessible to ground machines, and to treat such infested areas with a speed quite impossible by any other means.

Another method of dealing with pests is by biological control. This means spreading harmless insects which will live on the pests and reduce their numbers. This sort of thing can be done most efficiently by air, in fact it can also be done unintentionally, with harmful results. For instance, before starting the South Africa-Australia air service it was discovered that there were 52 varieties of pests which existed in South Africa but not in Western Australia, which were liable to be transported inside or outside the aircraft on that route.

5. Aircraft in Surveying

Considering the immense size of Canada, Australia and Africa, and the large proportion of unexplored country, it is not surprising that aircraft are used extensively in the survey of vast areas of unknown country. These surveys are made for a number of reasons apart from ordinary map-making. In Africa, 30,000 square miles were mapped for the purpose of choosing the best route for a projected railway line. 16,000 square miles were mapped in the Gold Coast for a hydro-electric scheme, and in Northern Rhodesia 11,000 square miles have been looked at for a possible extension of the copper belt. In India 180,000 square miles have been photographed for the survey of India. In Pakistan, under the Colombo plan, 300,000 square miles are to be photographed for geological and irrigation surveys.

Probably the most important aerial surveying is done for geological reasons. Aerial prospecting is indispensable in Canada and Australia and many interesting techniques have been developed. Geological interpretations of photographs, measurements of the Earth's magnetic field, measurements of electro-magnetism and measurements of radio-activity, all play their part in laying bare the hidden resources of those great countries.

Allied to geological surveys are the aerial soil surveys over country otherwise inaccessible, or where the use of land changes rapidly. Over- or under-developed land and soil erosion are quickly detected in photographs and volumes of timber per acre can be estimated with fair accuracy. Canada has led in the development of the technique of assessing the composition, wealth and best logging plan for her vast forests, using stereo-examination of photographs combined with ground work.

The great attraction of aerial surveying, for whatever purpose, is the speed at which it can be done and hence, the tremendous amount of time saved. For instance, before building the hydro-electric plant at Kitimat, in Western Canada, it was necessary to find the best route for a 50 mile power line across mountains 5,000 feet high. By any other method the survey would have taken three years but, using helicopters, the work was completed in thirty hours flying. Or again, the survey of the Frazer River Canyon in British Columbia, which took five years on foot, was completed in one season from the air.

As early as 1923 aerial survey was used in Canada to sketch waterways, lakes, rivers and areas of burn and merchantable timber. The cost was ½ cent per acre against 2½ cents for ground reconnaissance and it was done at the rate of 36 square miles an hour.

6. Aircraft for Freight

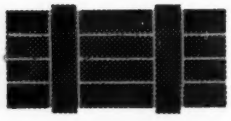
I think it can be generally assumed that aircraft are not employed on jobs which can be done more cheaply by other means. In the moving of freight, however, a whole host of complicated problems make the issue rather more difficult. I do not propose to deal with express air freight because, from the aircraft point of view, it is not so very different from passenger-carrying.

For many years there was a tendency in this country to think of air freighting as rather expensive and unnecessary. This is not altogether surprising considering the difficulties of weather, short distances and, in the early days, the relative lack of funds available to the aviation industries. There are now, I am glad to say, many welcome signs of growing interest in the rapidly expanding market for air freight.

Development was very different in Canada, for example, where as early as 1937 Canadian aircraft carried 24 million pounds of freight, compared with 9½ million pounds lifted by United States carriers in 1939.

Air freight opened the Canadian North in the 20's and 30's and every further development in that area depends entirely on aviation. Take, for instance, the Eldorado uranium mine at Port Radium on the Great Bear Lake, less than 30 miles south of the Arctic Circle. In the first place it was discovered by Gilbert Labine in 1930 from the air in an aircraft flown by C. H. "Punch" Dickens, a famous name among the bush pilots of Canada.

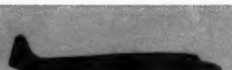
The mine at Port Radium is entirely supplied by air from Edmonton, 1,200 miles away, except for particularly large or heavy equipment. The Eldorado Company also looks after another establishment at Beaverlodge, 350 miles from Edmonton. The Company operates one Dakota and one Curtiss Commando which, between them, lift on the average 3,000 passengers and about 3,000 tons of freight every year. A total of roughly 2½ million ton miles at a cost of 22½ cents per ton mile. The only other transport system is by water, and although this is considerably cheaper—it costs $80 for every ton taken to Port Radium compared with $225 per ton by air—navigation to Port Radium is only open for one month and to Beaverlodge for four months in



3000 TONS

3000 PASSENGERS

Total: 2,500,000 ton miles



Figures not available	$80 per ton
22½ cents per ton mile	$225 per ton
15 cents per ton mile	Figures not available

Air Operations of the Eldorado Company in Northern Canada. *Eric Strachan*

the year. Therefore, allowance must be made for the cost involved in carrying large inventories of waterborne freight and equipment. In fact, the water route is only used to bring out the products of the mine.

The figure of 22½ cents per ton mile becomes rather more interesting when it is compared with the cost of road transport over comparable distances in Northern Canada, which is, at a rough estimate, about 15 cents per ton mile, although the average for the whole of Canada is 5½ cents per ton mile.

Two of the reasons why this Company can operate at such a relatively low cost are that both aircraft were picked up cheaply as war disposal and because of the large back haul of passengers and concentrates which make for the high load factor of 90 per cent.

The important point here is that these establishments, thanks to aircraft, are in no way cut off from the outside world. Since fresh food and vegetables, newspapers and books can be flown in all the year round, the community which includes several families, lives a normal full life.

Passing now from Canada to Australia, where an experiment has been running some six years on the flying of beef from a cattle station to the coastal port. These cattle stations can be up to five million acres in extent and 500 miles from the nearest railhead or harbour.

The experiment was started by Air Beef Ltd., who established an experimental abattoir at Glenroy, some 180 miles inland from Wyndham in the north-west corner of Western Australia, with a capacity for dealing with 60 head of cattle per day or 300 a week. During the six years an average of 4,000 head of cattle per annum have been killed and the result has been to upgrade the meat from 23 per cent. export quality, to 65 per cent. export quality, and total frozen carcass weight has gone up 13 per cent. Before the introduction of Air Beef only about 7 per cent. of the cattle raised ever reached the meat works. Although the value of the meat has only gone up by 34/- a head, the increased production of meat has increased revenue by over 200 per cent. The number of cattle marketed from that station has doubled and the station has been enormously improved by the increased income and by using the aircraft to transport to the station all the equipment required for the development.

The possibilities for Australia are immense. It has been estimated that by using inland abattoirs and air freighting, beef production in Australia could be doubled in ten years.

There is one other use for air freight which I would like to mention. It is in connection with the giant construction jobs in remote districts. Early this year a 350-mile railway from the St. Lawrence to Knob Lake on the border of Quebec and Labrador was completed to carry iron ore. This railway is capable of carrying trains weighing up to 10,000 tons. The railway was built principally by air. Using six landing strips, men, equipment and food were flown to work on various sections of the line. I have already mentioned that helicopters were used to survey the route for the power line from Kemano to Kitimat. I think it is worth mentioning here that the line was also built with the use of helicopters, which carried every man and piece of equipment to remote spots up to 5,000 ft. above sea level.

7. Aircraft for Other Uses

I have tried to describe to you the major fields of employment for aircraft other than fighting or passenger-carrying. There are one or two fields which do not fall into any category but which ought to be mentioned.

There is the Flying Doctor Service in Australia, which has made such an enormous difference to life in the outback. I am not going to describe the organisation, except to point out that the pilot has a lot of problems which normally do not apply. The mere fact that weather or airfield conditions are such that normal flying would cease, does not matter very much when a life is at stake. The pilot often has to make decisions, knowing that if anything happened to the aircraft it would not be covered by the insurance. Emergencies are much more likely to occur after floods or storms just when air strips are at their worst. Night flying is not possible at present, so there is the added hazard of not getting back in time and having to make a forced landing in the desert. The Flying Doctor Service is a wonderful achievement but flying the doctor is no " piece of cake."

In the exploration for, and production of, oil, Shell have five aircraft in British Borneo which are used to carry staff between oilfields, camps and the nearest major airport at the rate of about 1,000 a month. Journeys which would take 14 to 20 hours on the ground are done in 50 minutes by amphibian.

Quite apart from the practical advantages, the moral effect on staff of the ability to extricate casualties from difficult places and get them quickly to hospital has been one of the most welcome results of using aircraft. For instance, a suspected typhoid case was in the main base hospital within five hours of the emergency message being received. The outstation was 200 miles away and the surface journey would have taken 24 to 36 hours.

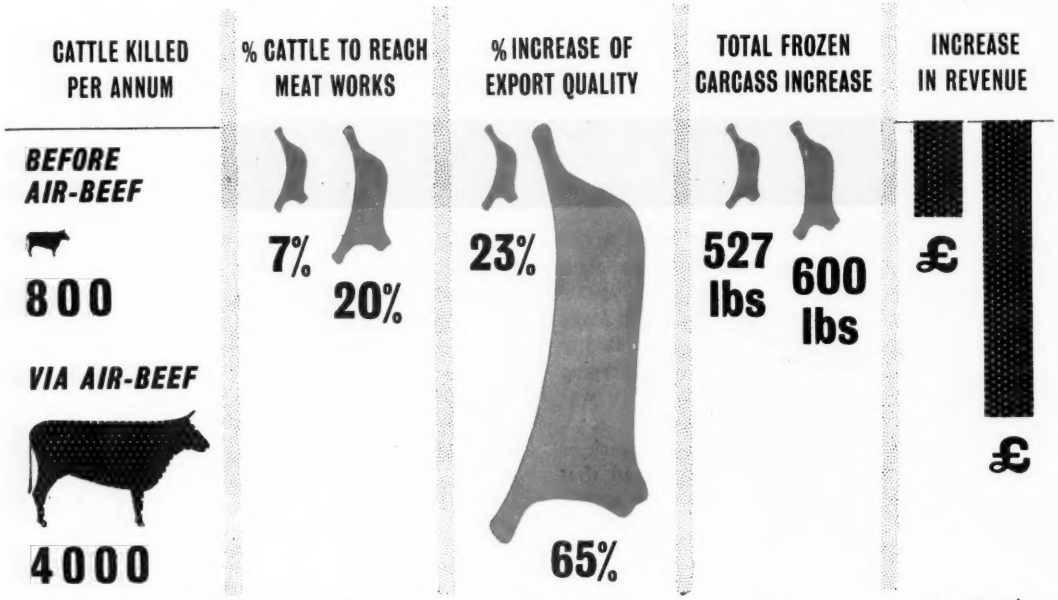
Much as I would like to say something about the private owner and flying for fun, I am afraid that the subject is too big and complicated to be dealt with here.

In spite of the claims I have made for the contribution of aircraft to the progress of civilisation, I must admit that there are other uses not quite so Utopian.

At Yellowknife in Canada this year, a man succeeded in pinching two gold bars which he put in his kit bag. He then hired an aircraft and flew off to Edmonton and vanished. The story goes that the pilot helped him to lift his bags into the aircraft and when he felt the weight he is supposed to have said: " What have you got in there—a couple of gold bricks? "

HELICOPTERS

I have deliberately avoided the subject of helicopters simply because the relative expense at present puts them out of the reach of most people. However, now that they have caught the imagination of the public and official mind I have no doubt that their development will not lag through lack of interest or funds. Neither



The Effects of the Air-Beef Scheme in Australia. *Eric Strachan*

does it need a particularly vivid imagination to think of the uses for helicopters, once they can be produced reasonably cheaply.

I also do not wish to become involved in an argument about the use of helicopters, but judging by present trends it looks as if this country particularly could benefit from their characteristics. Fixed-wing aircraft are ideal for agriculture, pest control and survey so long as the geographical scale of countryside is large. When it comes to dealing with small detailed work, which is the rule in this country, then the helicopter is the only really useful type of aircraft for that purpose. In fact, the greatest part of air spraying in this country is done by helicopters and some thousands of acres of potatoes are sprayed by helicopters each year.

8. Requirements

That really concludes my rather sketchy summary of what aircraft are used for in the Commonwealth and Empire.

There are several conclusions to be drawn. The first and most important is that, apart from the Bristol Freighter and the Beaver, and later the Otter, not one single aircraft used in any of the fields I have mentioned was actually designed for the job. Every sort and kind of aircraft are used from Moths to Dakotas and they are all old and were all designed for something else. It is like using a double decker 'bus as a milk float, or a Bentley as a farm tractor.

It is also perhaps interesting to note that both the Freighter and the Beaver were private ventures, the latter being designed and built in Canada. I may be wrong, but so far as I know the only aircraft on the stocks which falls into the category I am discussing, is the Twin Pioneer—known to some as the "Double Scotch." This started as, and is still, substantially a private venture; it was designed and is being built by a Company that has only produced one type of aircraft previous to this effort. I think it is worth remembering that when the Beaver was first mooted the makers went to considerable trouble to find out exactly what the bush pilots of Canada really wanted and throughout its development their opinions, experience and criticisms were sought and used. The result is an aircraft which they like and use; 113 Beavers and 51 Otters are in use in Canada already. Not unnaturally, these aircraft are in demand outside Canada also.

Several attempts are being made to produce a DC-3 replacement, notably the Herald in this country, but it is not an easy thing to do because the DC-3 will only be replaced by an aircraft which is better in all respects and, most important, considerably cheaper to operate.

The secret of success seems to be the very closest co-operation between the makers and the operators. That co-operation exists in the development of air liners, it is not always present in the development of aircraft for the outback.

"The "Civil Aviation Journal" of New Zealand introduced an article with these words:

"While it is not usually the policy of the Civil Aviation Journal to reprint articles from other publications this article is so apposite to a major problem of concern to operators in New Zealand that we have on this occasion departed from normal policy. Acknowledgment is made to the publishers of 'Aviation Age' for permission to reproduce this article."

The Journal then prints an article called "We Want a Flying Tractor." I will not weary you with details but the author wants an aircraft of one ton capacity, a biplane, low wing loading, load and engine ahead of the pilot, no flaps or slots, simple, low speed and price.

In fact, an aircraft obviously based on these requirements has been built in America and is expected to cost between £5,000 and £6,000. Trials already indicate that using this specially designed aircraft the operating cost of chemical application is roughly half that of the cost of the best existing aircraft converted for the purpose. The other interesting fact is that a third of these aircraft to be built will probably be sold to New Zealand. I have also heard that more than one British aircraft company is giving careful attention to the needs of New Zealand's top-dressers and aerial agriculturalists.

From Australia I would like to read an extract from a letter from the Operations Supervisor of Connellan Airways at Alice Springs who, among other things, run the Flying Doctor Service there:

"The one difficulty which is faced by bush airline operators is the lack of a suitable type of aircraft. At the moment there is no aircraft being manufactured, nor as far as is known, is one even contemplated. Tough conditions are experienced and the aircraft must be designed for the job. Specifications for such an aircraft, the 'Brolga,' were published in the Australian 'Aircraft' magazine in 1950 and were sent all over the world to manufacturers. A great service would be done to bush operators, not only here, but in other undeveloped parts of the world if this need could be presented to the aircraft manufacturers, for then it is possible that such a suitable aircraft could be produced."

From Canada, Eldorado Aviation have this to say:

"We are now using aircraft which are approaching obsolescence. We must shortly consider replacement. At the present time there is no new aircraft available which meets our requirements. This is a problem which is common to all operators in Canada serving remote areas. Possibly the best commentary on the failure of the aircraft industry to meet this particular demand is the fact that DC-3 aircraft now command a higher price on the market than they did in 1946."

So far as the British Aircraft Industry is concerned, out of 687 aircraft of 64 different types employed on bush operations in Canada in 1953, only 46 were built in this country and only 4 were built after the war.

Quite obviously this is only one side of the picture and no one would deny that the makers have their troubles and difficulties too. After all, even pilots and operators are not well known for being able to state and stick to their requirements, although they can be relied on to say with considerable emphasis what they do not want. But the fact remains that aircraft are needed for these operations, that aircraft will be used for these operations and somebody has got to make them.

There can be no doubt that aviation is an essential element in the development of the Commonwealth and

Empire. Hence it follows that aircraft must be designed for the jobs for which they are required, or the aircraft must be highly versatile. That, whatever the job, the aircraft must be simple, robust and easy to maintain. That speed is a secondary consideration for the simple reason that even if they only flew at 30 knots they would still get to places several months before dog teams or ox carts. This does not mean that aircraft have got to be slow. If high speed makes them more economical to operate, so much the better.

Eventually, of course, in anything of this sort the question of relative cost creeps in and quite rightly. This applies equally to bush or outback operations as it does to the movement of heavy freight over long distances. The difficulty about estimating the cost of this type of aviation is that it is very difficult to find comparable figures. In Northern Canada the cost per ton mile by air is not much greater than by road, but that takes no account of the cost of the road in the first place, or its maintenance. In Australia the railways, as in quite a number of countries, are run at a loss, yet quite obviously they must go on running.

The difficulty at the moment seems to be to estimate correctly exactly what type of operations are most suited to each system of transport. The conclusions, as I see it, are that the scope for aviation will be considerably broadened: first, when the full advantages and possibilities of aircraft are thoroughly appreciated and trusted by potential operators, and second, if and when suitable aircraft make their appearance.

Although it is really outside the scope of this lecture, I must draw attention to the very great importance of a strong flexible air cargo fleet in the event of war. After all, it is the combination of the Navy and Merchant Navy which constitutes our maritime strength. Similarly, our power in the air depends upon the combination of the Air Forces and the Merchant Air Fleets of the Commonwealth.

9. Conclusion

At the risk of becoming monotonous I would like to repeat that aviation has become a vital and integral part of the civilisation of the countries of the Commonwealth and Empire and that their further development depends upon operators demanding, and the Aircraft Industry producing, machines capable of doing a wide variety of work cheaply and efficiently.

At the moment, the centre and head of the aviation industry for the Commonwealth and Empire is in these islands. It is true that great strides have been made in some of the Dominions in the design and production of aircraft suited to their own needs, but the Industry in these islands is still the leading partner and capable of making many useful contributions for a number of years yet. If it is to do this it must not be blinded by the chances of lucrative Ministry of Supply contracts, or have its attention to the requirements of the Commonwealth and Empire distracted by the clamour of Britain's airline operators. The Ministry of Supply, the Service Ministries and the civil operators are obviously the Industry's best customers and patrons, and they cannot be blamed for only considering their own special requirements. But if the Industry is to play its proper part it must look beyond that and consider the progress of aviation as a whole and all over the world.

I have no intention of telling them how this can be done. All I wish to do is to draw attention to what I think has become a neglected part of aviation. What is more, it is that part of aviation which has the most important part to play in opening up the remote areas of the new world.

It rather looks as if I have placed all the burden of the future development of outback and bush aviation on the makers. That is not the impression I want to leave. It is much more important that each party concerned should understand and appreciate the demands, difficulties and limitations of the others and of aviation in remote areas in general.

I started the preparation of this lecture thinking it was going to be quite a burden, but thanks to the wonderful help I have had from people all over the Commonwealth and Empire, I have learned more about aviation than I could have done in any other way. For that reason I owe a debt of gratitude to the Royal Aeronautical Society for asking me to give this lecture. I have also acquired an even greater admiration for the pilots and operators of aircraft in my third division of aviation. All over the world they are doing their work without fuss or fanfare, without publicity or uniforms, and nearly all of it is done with makeshift equipment.

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The Evolution of Arctic Airways

by

JOHN GRIERSON, F.R.G.S.

The North-West Passage

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Empire. Hence it follows that aircraft must be designed for the jobs for which they are required, or the aircraft must be highly versatile. That, whatever the job, the aircraft must be simple, robust and easy to maintain. That speed is a secondary consideration for the simple reason that even if they only flew at 30 knots they would still get to places several months before dog teams or ox carts. This does not mean that aircraft have got to be slow. If high speed makes them more economical to operate, so much the better.

Eventually, of course, in anything of this sort the question of relative cost creeps in and quite rightly. This applies equally to bush or outback operations as it does to the movement of heavy freight over long distances. The difficulty about estimating the cost of this type of aviation is that it is very difficult to find comparable figures. In Northern Canada the cost per ton mile by air is not much greater than by road, but that takes no account of the cost of the road in the first place, or its maintenance. In Australia the railways, as in quite a number of countries, are run at a loss, yet quite obviously they must go on running.

The difficulty at the moment seems to be to estimate correctly exactly what type of operations are most suited to each system of transport. The conclusions, as I see it, are that the scope for aviation will be considerably broadened: first, when the full advantages and possibilities of aircraft are thoroughly appreciated and trusted by potential operators, and second, if and when suitable aircraft make their appearance.

Although it is really outside the scope of this lecture, I must draw attention to the very great importance of a strong flexible air cargo fleet in the event of war. After all, it is the combination of the Navy and Merchant Navy which constitutes our maritime strength. Similarly, our power in the air depends upon the combination of the Air Forces and the Merchant Air Fleets of the Commonwealth.

9. Conclusion

At the risk of becoming monotonous I would like to repeat that aviation has become a vital and integral part of the civilisation of the countries of the Commonwealth and Empire and that their further development depends upon operators demanding, and the Aircraft Industry producing, machines capable of doing a wide variety of work cheaply and efficiently.

At the moment, the centre and head of the aviation industry for the Commonwealth and Empire is in these islands. It is true that great strides have been made in some of the Dominions in the design and production of aircraft suited to their own needs, but the Industry in these islands is still the leading partner and capable of making many useful contributions for a number of years yet. If it is to do this it must not be blinded by the chances of lucrative Ministry of Supply contracts, or have its attention to the requirements of the Commonwealth and Empire distracted by the clamour of Britain's airline operators. The Ministry of Supply, the Service Ministries and the civil operators are obviously the Industry's best customers and patrons, and they cannot be blamed for only considering their own special requirements. But if the Industry is to play its proper part it must look beyond that and consider the progress of aviation as a whole and all over the world.

I have no intention of telling them how this can be done. All I wish to do is to draw attention to what I think has become a neglected part of aviation. What is more, it is that part of aviation which has the most important part to play in opening up the remote areas of the new world.

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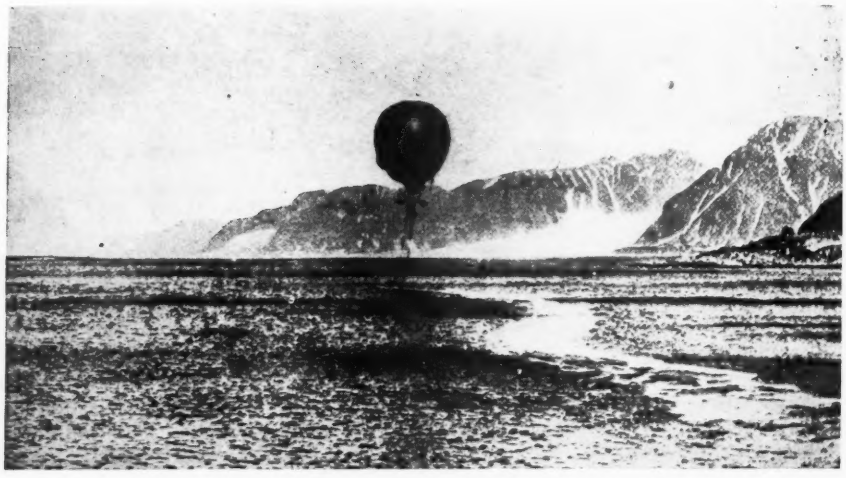


Dr. Andree and his two brave companions in the *Eagle* over Virgohamna, Spitzbergen, 1897; the balloon has recovered after striking the sea at its launch from Spitzbergen.

(Courtesy of the Scott Polar Research Institute)

also been the first man ever to reach the South Pole) determined to try a flight over the North Pole. In May 1925, together with the American Lincoln-Ellsworth, he left Spitzbergen with two Dornier flying-boats, each carrying three men.

All went well until they reached 88° where engine trouble forced one boat to land on a lead of open water in the ice. The other machine got down safely, but before they could take off in the serviceable aeroplane, the lead filled with pack ice. Only one way of salvation remained—to prepare a smooth enough runway over hummocky ice for a flying-boat to take off. To make such a strip, no more than 500 yards long, took the marooned men over three weeks, and when the Dornier eventually staggered into the air, Amundsen's party missed crashing among the ice boulders by the narrowest margin. Before reaching Spitzbergen, they were forced to land in the sea and finished the last few miles by taxying over the water.

Amundsen's Airship and Byrd's Trimotor Triumphs

Besides the aeroplane there was another aerial vehicle, the airship, which had been developed during the war and which seemed to offer better range possibilities for Trans-Polar flying. In May 1926, Roald Amundsen again prepared for a Trans-Polar flight, this time in a semi-rigid airship of Italian manufacture, called the *Norge*, accompanied by its designer, Umberto Nobile. Amundsen's starting point was Kings Bay in Spitzbergen, but he was surprised to find that Commander Byrd, of the U.S. Navy, had arrived in Spitzbergen with a three-engined Fokker before the airship was ready to go.

After all his previous endeavour, Amundsen deserved to be the first man over the Pole, but this was not to be for on 9th May Byrd set off and in a brilliant flight of 15½ hours, at an average height of about 3,000 ft., flew over the Pole and back to Spitzbergen. This was undoubtedly the greatest feat of aerial navigation in the first quarter century of flight.

A day later Amundsen set out in the *Norge*. He not only flew over the Pole but went right across the Polar Basin to Alaska, where he landed at Teller on the Bering Sea, having covered 3,000 miles in 71 hours.

Subsequently, Nobile, who had been made a general and a marquis by his jubilant countrymen for the part he had played in this flight, quarrelled with Amundsen over the credit for the leadership of this expedition.

Roald Amundsen's Dornier Wal N 25 flying-boat on the frozen surface of the Arctic Ocean. With no proper tools Amundsen and his men made a 500 yard runway for the flying-boat's take-off.

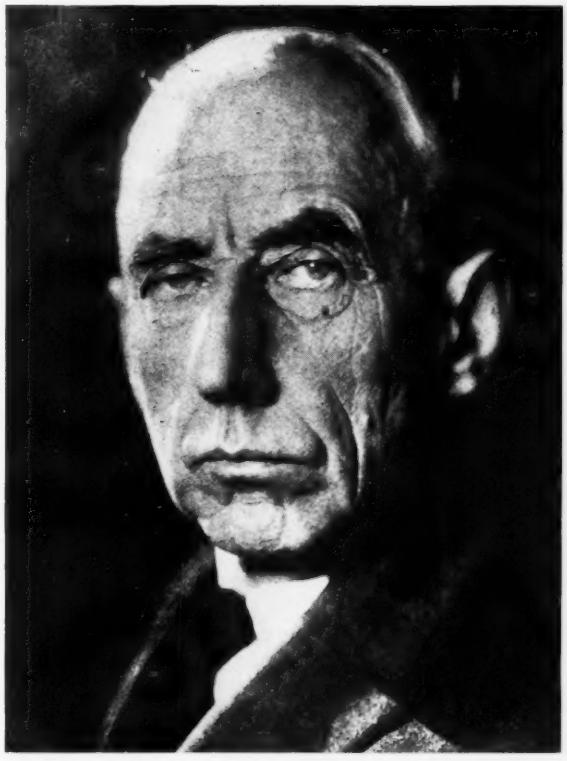
(From "Air Pioneering in the Arctic" by Amundsen and Ellsworth: Courtesy of the publishers, National Americana Society)

The Nobile Disaster

Two years now passed before Nobile himself, captaining the airship *Italia*, began from Spitzbergen the most disastrous flight in Arctic history. After crossing the Pole successfully, where he dropped the Papal and Italian flags, Nobile encountered icing so serious that the particles flung off the propellers began to penetrate the envelope. In the resultant crash, the main gondola containing ten men was flung on to the ice, breaking the legs of Nobile and one other crew member, but the rest of the stricken ship with six aboard was carried off and never seen again. Three of the survivors set out on foot hoping to reach the North Cape; one of them perished and the other two were later rescued by the Russian ice-breaker *Krassin*.

Captain Ejnar Lundberg, a Swedish pilot, flew a two-seater Fokker IVD skiplane from Spitzbergen, located the scene of the *Italia's* crash, and landed on the ice. After successfully flying off with Nobile (who had arrived on the ice clad in full dress uniform and wearing a sword) and his dog, the biplane was capsized on the return journey through landing on rough ice. The pilot was therefore marooned with the eight survivors (one of this party having died) from the airship, but fortunately the *Krassin* managed to force a passage and rescue the whole party.

To the sufferings and losses of Nobile's men, a far greater tragedy was added by Roald Amundsen himself who, in spite of Nobile's previous quarrel with him, went out to join in the search, and whose Latham flying-boat was lost without trace between Bergen and Spitzbergen. An Italian Court of Enquiry was held in 1929, and found Nobile responsible for the loss of the *Italia*; he was then forced to resign all his previous honours.



(Courtesy of the Scott Polar Research Institute)

Roald Amundsen, one of the greatest sons of Norway.

Commander Byrd (*centre*) with (*left*) Lieut. G. O. Noville and (*right*) Floyd Bennett at Spitzbergen about to enter their Fokker tri-motor on the start of the first flight over the North Pole in 1926.

(Copyright, National Geographic Society; Courtesy, National Geographic Magazine)

The crews of the three U.S. Army Air Service "Round-the-World Flight," 1924, in front of one of the DT-2s. Left to right: Captain Lowell Smith, Lieutenants C. P. Arnold, H. H. Ogden, J. Harding, Leigh Wade and Erik Nelson.

Nobile's *Italia* at Ny. Alesund, Vestspitsbergen, before being launched on her disastrous voyage to the North Pole.

(From "The Polar Adventure" by Odd Arnesen: Courtesy of the author and the publishers, Victor Gollancz Ltd.)

American Pioneering of the Lower Arctic

While long range flights were proving so difficult in the Far North, it had been noticed that the lower Arctic had another attraction; it provided as a bridge across the North Atlantic a series of stepping-stones so spaced that the stages might fall within the range of existing aircraft design. Such a possibility had first been demonstrated as long ago as 1924, when the American Army Round-the-World Fliers made the attempt to cross the North Atlantic by way of Iceland and Greenland. Their machines consisted of Douglas DT-2 biplane seaplanes, each powered by a single 400 h.p. Liberty engine; and the extraordinary success which this enterprise achieved with very primitive equipment has received less than its fair share of acclamation on either side of the Atlantic.

Three machines left Kirkwall, Orkney, on the 2nd August 1924 for Hornafiord, Iceland. Thence their route lay *via* Reykjavik, Frederiksdal, and Ivigtut (South Greenland), Icy Tickle (Labrador) to Hawkes Bay. Their mission was accomplished in 32 days with the loss of only one aeroplane, which force-landed with engine trouble south of Iceland: the crew were saved.

In spite of this successful flight (which admittedly had been achieved with a narrow margin of safety) neither the American Army nor the American Government showed any immediate interest in following it up. Apart from private ventures, such as the flight by Cramer in the Sikorsky amphibian "Untin Bowler" which set out from Chicago and was crushed to destruction in the ice at Port Burwell, Labrador in 1929; the ill-planned 1932 attempt of the Hutchinson flying family whose Sikorsky flying-boat was wrecked in the ice on the East Coast of Greenland; and the second try of the sporting individual Cramer, whose small Diesel-engined Bellanca seaplane was lost without trace on the high seas in 1931 on the last lap between Shetland and Norway—apart from these, American aviation endeavour in the lower Arctic was dormant for nine years.

But in the extreme north, American airmen had outshone all others by Byrd's flight in the race for the Pole.

Hubert Wilkins' Crossing of the Arctic Basin

Another flight almost as remarkable as Byrd's was that of Hubert Wilkins, the great Australian explorer, who, with a Norwegian pilot, Lieut. C. B. Eilsen, in April 1928 flew a single-engined Lockheed Vega skiplane from Alaska to Spitzbergen *via* Ellesmere Land, a distance of 2,200 miles in 20 hours.

British Arctic Flying

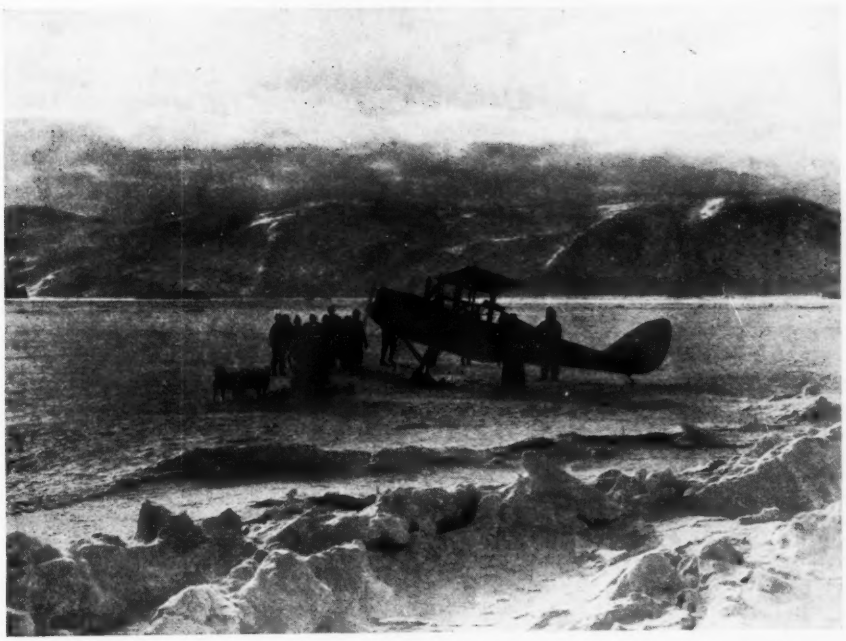
In the meantime, British interest in Arctic flying found an advocate in Gino Watkins. Watkins, who was far more an explorer than an airman, had been casting around for a reason to take an expedition to the Arctic when he hit on the idea of making Arctic Air Routes the theme which could reasonably and usefully justify his ambition. He learnt to fly with the Cambridge Air Squadron and, at the age of 25, he sailed for East Greenland in 1931 as leader of the British Arctic Air Route Expedition; this was to be the first serious investigation of flying in the Arctic throughout every month of the year.

With Air Ministry support (which consisted of loaning two R.A.F. officers and obtaining a 15 per cent. price reduction on the aircraft), the British Arctic Air Route Expedition sailed from London in the *Quest*, a wooden vessel of 300 tons, for East Greenland and set up their base at Lake Fiord, some 40 miles west of Angmagssalik. Their aircraft consisted of two 85 h.p. de Havilland Gipsy Moths (seaplanes or skiplanes), equipped with special long range tanks, since the original intention was for these machines to carry out a route survey right through to Winnipeg: this part of the plan was thwarted by gale damage to the aircraft, but in spite of these mishaps many local air reconnaissances were made. These were backed up by sledging parties, one of which went right across the Ice Cap to the West Coast.

An important objective of Watkins' expedition was the establishment of a station for meteorological observations on the top of the Greenland Ice Cap. The double dome-shaped tent for this was pitched 130 miles from base at a height of 8,000 ft. and was manned throughout the winter for six months. Owing to a misunderstanding at home, the impression was given that

(*Left*) Sir Hubert Wilkins' Lockheed Vega skiplane being hauled by huskies from the trading post at Barrow to the starting point for his flight to Spitzbergen.

(*Reproduced from The Geographical Review, Vol. 18, 1928: Courtesy of the American Geographical Society*)



(*Right*) Forerunner of today's airline. A D.H. Gipsy Moth skiplane of Watkins' British Arctic Air Route Expedition of 1930-31 on the ice of Baer Fjord, East Greenland.

(*Courtesy of the Scott Polar Research Institute: Copyright Gino Watkins Memorial Fund*)

the difficulties in relieving Angust Courtauld during his watch in the tent amounted to an emergency. As a result, Captain Ahrenberg, the Swedish aviator (who in 1929 had attempted the flight from Stockholm-New York but had been forced by engine trouble to give up at Ivigtut), flew a Junkers seaplane *via* Iceland to Watkins' base at very short notice, but by the time he arrived Courtauld's relief had already been effected by Watkins' sledging party.

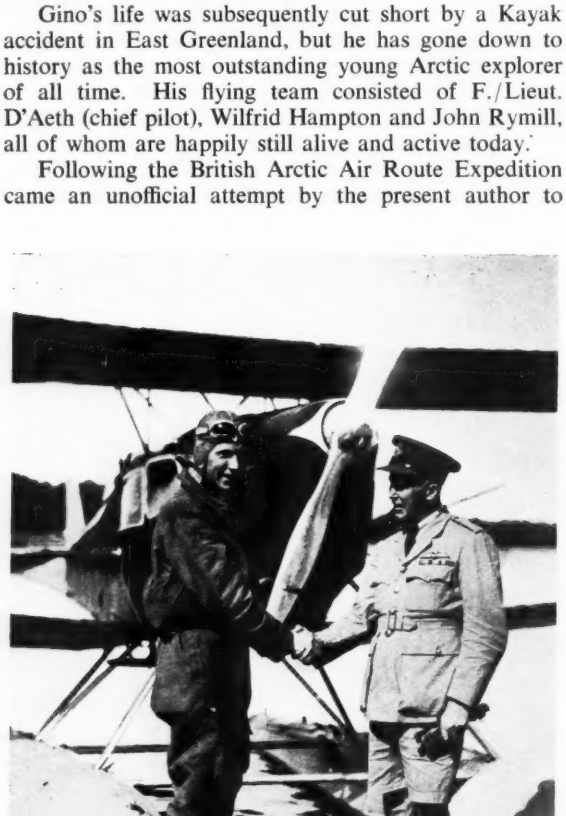
A Saunders-Roe Cloud flying-boat with better range possibilities than the small seaplanes was promised from England but never materialised. This might have been used for a survey along the whole Arctic Air Route as then envisaged, an achievement which would have put the seal on the other work of the expedition. But the observation from the air and from the ground of climatic conditions over a whole year on the East Coast of Greenland, which was their foremost aim, together with the results of long sledging reconnaissances to Cape Farewell and across the Ice Cap, actually laid the foundation of all Arctic air routes.

Gino's life was subsequently cut short by a Kayak accident in East Greenland, but he has gone down to history as the most outstanding young Arctic explorer of all time. His flying team consisted of F./Lieut. D'Aeth (chief pilot), Wilfrid Hampton and John Rymill, all of whom are happily still alive and active today.

Following the British Arctic Air Route Expedition came an unofficial attempt by the present author to make a survey flight along the route. This undertaking was distinguished by the facts that it took the longest period of any Arctic flight to accomplish—390 days from the first start at Brough to the final landing in Ottawa, involved the greatest number of crashes—two at Reykjavik and one at Ottawa—and was the only solo flight to the Arctic ever attempted before the Hitler War. Originally in 1933 an 85 h.p. Gipsy Moth seaplane was used, and the hops Brough—Kirkwall—Thorshavn (Faeroes)—Reykjavik were more or less successfully accomplished, although, thanks to sticking exhaust valves, part of the last leg had to be flown on three cylinders—and in bad weather. After repairs to the engine in Iceland, the machine was capsized and wrecked while taking off in a rough sea for Greenland.

Next year a bigger and better aircraft—a Fox Moth called *Robert Bruce* of 120 h.p. was used. The flight began from Rochester, the nearest seaplane base to London, and went by way of Londonderry to Reykjavik. Here during an attempted take-off, *Robert Bruce* struck a rowing boat and the pilot had to return to England by sea, in order to fetch a new wing and take one float for repairs. The next take-off for Greenland was successful, but trouble was experienced in picking out Angmagssalik (a settlement of 53 eskimos). After flying unknowingly right past this East Greenland metropolis, the pilot was lucky to spot a small fiord free of ice. He therefore sent out an S.O.S. on his short-wave transmitter, and landed to await events. Eighteen hours later he was reached by a party of eskimos under Pastor Rosing and given directions for finding Angmagssalik, which was about 20 miles away.

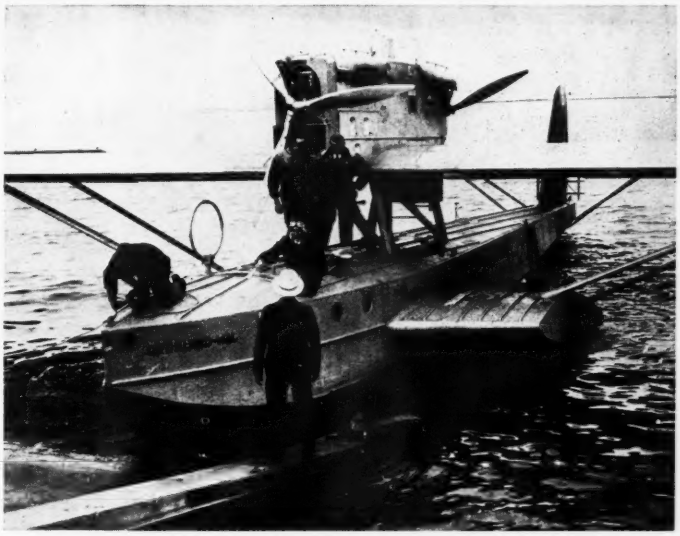
From Angmagssalik two abortive attempts were made to fly across the Ice Cap, each time *Robert Bruce* being forced back by bad weather. However the third endeavour was successful, and the flight over to Godthaab was made in exceptionally fine conditions. After that the flight ran without serious incident from Godthaab to Lake Harbour (Baffin Land)—Povungnituk—Fort George—Eastmain and finally Ottawa, which was reached on the 30th August 1934. Then, during a flight after overhaul, a crash occurred in landing on the glassy calm Ottawa River, so for the final hop to New York the floats were replaced by wheels. This was actually the first flight from London to Ottawa.



The Author on his arrival at Ottawa in his D.H. Fox Moth *Robert Bruce* in 1934, being welcomed by the R.C.A.F. Station Commander.

German Interest

Although the British had made the first trans-Atlantic airship flight with the R.34 in 1919, the Germans entered the field of long distance airship operations in 1924 when Dr. Eckener took the LZ.126 across the North Atlantic, followed by the *Graf Zeppelin* in 1928. By 1930 the Germans also had in the Dornier Wal a flying-boat capable of surveying the Arctic Air Route, and under the command of Wolfgang von Gronau they began to operate a series of surveys through Iceland and Greenland. The most ambitious one, in 1931, involved a flight across the Inland Ice (which was believed to reach up to 11,000 ft.) between Scoresby Sound and Sukkertoppen, a remarkably difficult 4-hr. hop for the flying-boats of those days. Gronau related



von Gronau with one of the Dornier flying boats used by him on his comprehensive Arctic survey flights.

(Courtesy Dr. von Gronau)

that at one stage, when he thought he was at least 1,000 ft. above the Ice Cap, his radio operator reported that their aerial was trailing in the snow.

During July of the same year, Dr. Eckener took the *Graf Zeppelin* on a successful reconnaissance of the Polar Basin. He went from Spitzbergen to Franz Josef Land, where he tethered his ship to a Russian ice-breaker for a spell in order to deliver mail, before proceeding farther east to Severnaya Zemlya and returning to Germany. This was the last airship flight ever to be made in the Polar regions.

These flights, sponsored by the German Government, were the first serious attempts to survey an Arctic Air Route between the Old World and the New. The routes of Gronau's flights were as follows:—

1930—Lyst on Sylt, Trangisvaag (Faeroes), Reykjavik, Ivigtut, Cartwright, Queensport, Mary-Joseph, Halifax, Nova Scotia.

1931—Lyst on Sylt, Trangisvaag, Reykjavik, Scoresby Sound, Sukkertoppen, Godthaab, Povungnituk, Port Harrison, Long Lake, Chicago.

1932—Lyst on Sylt, Seydisfiord (Iceland), Reykjavik, Ivigtut, Cartwright, Montreal, Ottawa, Detroit, Chicago.

By way of contrast to the flights of von Gronau, which had been planned and executed with Teutonic thoroughness, was that of Hirth and Weller in 1930. They flew a Klemm monoplane with a 40 h.p. Salmson engine and declared, when they left Kirkwall (Orkney), that their destination was New York. After flying 11 hrs. 20 mins. they landed successfully in a small rough field at Kaldadarnes, some 30 miles S.E. of Reykjavik. But with such light hearts had these two aviators set out on their long flight, that they had omitted to seek permission from Denmark to land in the "closed country" of Greenland.

The reason for the closing of Greenland except to specially authorised persons was two-fold: to protect the eskimos from disease since their resistance is low, and to limit the liability of the Danish Administration in the event of search and rescue becoming necessary.

So Hirth and Weller were up against a major political difficulty for their next hop, but even more serious was the fact that the coast of East Greenland completely lacked any flat ground where a land aeroplane could alight. In these circumstances the two had no alternative but to continue their journey westwards by ship. However, they had been the first men to land a landplane in Iceland, a feat which none else on a flight from outside the country emulated until after the outbreak of Hitler's War.

Italo Balbo, whose leadership was responsible for the impressive formation flight of 24 Savoia flying boats from Orbetello to New York in 1933.

The Italian Armada

The most publicised of all Arctic flights before the 1939-45 War was the mass formation of 24 Savoia Marchetti flying-boats, led by General Italo Balbo, which in the summer of 1933 flew from Orbetello to Chicago in 14 days with the loss of only one machine. This crashed when landing on calm water at Amsterdam. Their route was *via* Amsterdam, Londonderry, Reykjavik, Ivigtut, Cartwright, Shediac and Montreal.

Although this flight reflected a standard of organisation, daring and skilful execution of great credit to the Regia Aeronautica, it added little to what was already known about the route from the point of view of civil air development. Nobile's airship work remains undoubtedly Italy's greatest contribution to Arctic aviation.

The Lindbergh Surveys

Also in 1933, Pan American Airways decided to investigate the possibility of air routes over Greenland and Iceland. To this end they chartered a Danish cargo vessel, the *Jelling*, to act as base ship, and employed Charles Lindbergh and his wife to fly a single-engined Lockheed Sirius float seaplane. The flight survey which followed was easily the most comprehensive ever to be made of Greenland and Iceland. However, the consequent findings of Lindbergh had a sobering effect upon the optimistic, for this was the picture he presented.

Throughout the length of the Arctic Air Route as we then understood it (that is to say roughly a Great Circle route between London and the Middle West, or West of North America), there was not a single intermediate land aerodrome. The use of flying-boats or float-planes in northern harbours was limited to about three months in the year by ice conditions, and there was no aeroplane in prospect which, with a commercial load, could regularly take-off from ice and land on water, or *vice-versa*. Moreover the question of ground supplies in such places as the East Coast of Greenland and the Hudson's Bay area depended on the yearly voyage of a single ship. At that time few settlements in the Canadian Arctic had radio transmitters, so that day-to-day meteorological information over vast areas was non-existent. Admittedly the Arctic weather itself had proved to be less formidable than had been expected, and often of such a local nature that a Phön gale might blow in one place when there was calm only 60 or 70 miles away.

In the face of these generally bleak prospects the future seemed to depend on landplanes or flying-boats of far greater range than any then flying, able to cover the whole distance without refuelling. It was small wonder, therefore, that Pan American and air lines of other interested nations put the Arctic Air Route into cold storage, to await the evolution of bigger aeroplanes with longer range potentialities.

Russian Interest

With her Arctic coastline of over 5,000 miles, Russian thought has always looked to the North as a fertile field of development, and as hot air travels badly at these high latitudes, that development has had to be of a predominantly practical nature. While much had been done in the way of air reconnaissances along the coast of Siberia, it was not until 1937 that Russian achievements in the Arctic began to be shown to the world in all their seriousness.

The first sign was the Polar floating ice station devised and organised by Professor Otto Schmidt. (His name was later expunged from the record because of his unsatisfactory political views). The plan was to use Rudolf Island, in the Franz Josef archipelago as the main base and fly four men with nine tons of stores the 560 miles to the Pole. Transport consisted of four four-engined T4 Russian aeroplanes on wheel undercarriages.

The Lindberghs and their Lockheed Sirius seaplane, in which they had flown over Iceland and Greenland, on the Moscow River—1933.

(Planet News)

Owing to the fact that there is no land at the North Pole, any camp set up there will not remain at the Pole for long—it may in fact be borne along at anything up to half a mile per hour. Knowing this, Schmidt had Ivan Papanin and three companions established on an ice floe near the Pole. This drifted for nine months, until on reaching a point just north of Scoresby Sound on the East Coast of Greenland, the scientists were taken off by ice-breaker, having added greatly to the magnetic, meteorological and oceanographic knowledge of mankind.

While Papanin and his companions were being drifted along on their iceberg, Russia announced her intention of starting a commercial air service between Russia and North America across the Arctic Sea. By way of proving that this was no idle boast, Chkalov in June 1937 flew a single-engined Russian monoplane from Moscow to Vancouver, 5,300 miles over the Polar seas. This was followed next month by Gromov, who flew the same type of machine non-stop from Moscow to San Jacinto, California, a distance of 6,262 miles for which he claimed a world record. These flights, brilliant as they were, bore little resemblance to commercial requirements because the aircraft were single-engined.

It was therefore a harsh twist of fate which ordered the course of a further flight. This time the Russians used a four-engined T4 machine, so as to correspond with the normal formula of a long-distance civil aeroplane and ensure a good margin of safety even if an engine should stop. Levanevsky was the captain, and with a crew of five he set off from Moscow in August of the same year. Just after passing over the Pole, they reported engine trouble and then—silence.

The Search for Levanevsky

Now began the greatest search in Arctic history—far greater both in scope and in speed than anything that could have been done for Sir John Franklin, almost 100 years ago. The Russians appealed to Vilhalmur Stefansson to co-ordinate the effort from the American side and within a week air operations under Sir Hubert Wilkins began. For the first two months these could only be pursued in daylight, but after that they were carried on in moonlight, which in the Arctic actually gives clearer shadows than daylight. The Russians, of course, also ran their own searches from the other side of the Arctic. All was in vain, however, though a fitting tribute to Levanevsky's memory followed from the advance in knowledge of Arctic flying gained by this very extensive and prolonged air operation.

The First Forty Years of Arctic Flying

Hitler's War brought to an end the first great epoch of civil air development in the Arctic. Between the time of Andrée's balloon of 1897 and Levanevsky's four-engined aeroplane of 1937, lay forty years of spasmodic but determined endeavour. No chapter in the evolution of civil aviation can rival this, either in the courage of the air crews or in the skill of the navigators. In few fields of development have lives been more freely risked and given. Throughout the centuries the Arctic and

(From the Polar Record, 1939: Courtesy of the Scott Polar Research Institute: Copyright)

Four Russian scientists—*left to right*—E. T. Krenkel, I. D. Papanin, E. K. Fyodotov and P. P. Shirshov.

Antarctic have attracted to their surface exploration men of the highest calibre. By comparison, the years of aerial exploring and the numbers involved are far less, but aviators like Andrée and Wilkins can well keep company with Frobisher and Scott. In Roald Amundsen we had the pioneer explorer of both elements—the man first to reach the South Pole by sledge and first to cross the North Pole in an airship.

But no one nation can claim supremacy in this great work—its very greatness has demanded more. So, as we have turned the pages of the catalogue of the pioneers, we have seen Swedes, Americans, Norwegians, Italians, Germans, British and Russians all taking a hand in the aerial exploration of the Arctic during its first and most exciting phase.

Hitler's War—

The outbreak of war in 1939, when we in this island were to find ourselves so isolated and our lines of communication to the munition factories of Canada and the U.S.A. so strained, might logically have made us seek the benefit of the northern stepping stones. But in spite of appeals from members of Gino Watkins' Expedition, the Air Ministry showed itself entirely uninterested in the possibilities. So the problem was left to the Americans to tackle, when they came in 1941. This they did with their characteristic speed and determination.

A network of land aerodromes to cover Hudson's Bay, Baffin Land, Greenland and Iceland was planned for construction in the least time the short Arctic summer would allow. The very speed with which this conception was developed naturally resulted in mistakes—the outstanding one of which was the siting of Bluie West One in one of the worst weather areas of Greenland, but the project went through and a workable chain of aerodromes was established.

Between 1941 and 1943 landing strips were built at Goose (Labrador), Port Chimo (North Labrador), Frobisher Bay (Baffin Land), Narsassuak or Bluie West One (South Greenland), Sondre Stromfiord or Bluie West

Eight (West Greenland), Angmagssalik (East Greenland) and at Keflavik (Iceland). This gave the Allies a chain of seven aerodromes whereby thousands of aeroplanes from Canadian and U.S. factories were safely ferried over to the battle zones of Europe and Africa. Today the key aerodromes of that route remain on an operational basis and are being used for civil purposes, such as the ferrying of small British aircraft for sale on the American market, for military operations like the ferrying of Canadian and American fighter squadrons to Europe, and as weather and emergency alternates for airliners flying the regular North Atlantic routes.

— And After

The notable feature of the post-war years in Arctic aviation has been the profound shift of emphasis away from the civil field towards the predominantly military one. In fact between 1945 and 1952 not a single long-distance flight over the Polar Basin was made by a civil aeroplane. As soon as hostilities were over, the R.A.F. was quick off the mark with the flight of the *Aries*, a four-engined Lancastrian landplane, over the Pole from Iceland in 1945. The R.A.F. School of Navigation at Shawbury and Flying College at Manby then embarked on an extensive scheme of Polar flying, carrying out a number of reconnaissances in the vicinity of the Northern Magnetic Pole, as well as other Arctic surveys, first with Lancastrians and later with Canberras (the twin-jet bomber type of landplane).

In July 1945 the first jet flight across the Atlantic, by way of the Arctic Air Route, was made by six Vampires of No. 54 Squadron, which arrived at Goose just two days before an American Squadron of sixteen Shooting Star fighters took off on a flight in the reverse direction. More recently the British North Greenland Expedition has been revictualled by R.A.F. flying-boats and landplanes at Britannia Lake and beyond.

The U.S.A.A.F. can truthfully say that since the war they have "gone big" in the Arctic. Today North-Eastern Command owns a chain of aerodromes centred on Thule, in the N.W. corner of Greenland. There are Resolute and Alert in the Canadian Arctic Archipelago, Nord on the extreme north coast of Greenland, and the weather station T.3 on the ice somewhere between Greenland and the Pole.

The Great Air Base at Thule

Thule exemplifies man's challenge to the Arctic. Vilhalmur Stefansson has always preached the friendly nature of the Arctic, maintaining that the reputed severity of its climate is not justified in fact, and that the possibilities of foraging for food are almost every-

Ice-floes at the North Pole photographed from a DC-6B Viking of S.A.S. (Scandinavian Airlines System).

(Courtesy S.A.S.)

where existent. Contrary to general opinion, birds are found at the North Pole (Papanin's expedition there saw a guillemot), while polar bears appear miraculously in the ice wilderness attracted by the smell of human beings. In the sea there are seals and fish, and on rocks may be found edible herbs and lichens; to say nothing of animal life in the shape of Arctic fox, Arctic hare and the occasional musk ox. But while Stefansson has advocated living off the country in the Arctic, Roald Amundsen always spoke of its grim barrenness and harsh unfriendliness. Here at Thule we can see that the truth lies about half-way between these conflicting schools of thought. Seagoing ships can reach Thule during only two or three months of the year so that construction of the base had to be aided by an air-lift. In the twelve months from September 1951, 12,500 short tons of freight and 20,000 passengers were flown 2,000 miles from the main base of Westover, without accident.

Because the Thule subsoil is permanently frozen, normal foundations cannot be used. The technique is to mount all buildings on pads, consisting of unadulterated crushed rock. Air has to be ducted under the whole, in order to prevent the heat of the building from thawing the subsoil.

Thule's nine enormous hangars present a major problem in central heating at a spot where ground temperatures fall to $-50°C$. and winds can blow at over 120 m.p.h. Yet in spite of these extremes, visibility is generally excellent, little snow falls and only during June and July is there any trouble with fog. Bernt Balchen was responsible for the survey and planning of this base, which must rank as the most expensive and remarkable aerodrome in the whole world, glittering like a diamond in the Arctic night—a diamond invoiced to Uncle Sam at £96,000,000.

The Russian Enigma

Since the war the Soviet Unionists have remained extremely quiet about their Arctic work. The day when they would proclaim to all the world the achievements of Russian scientists and airmen seems to have vanished, like Papanin's iceberg. But it does not require a vivid imagination to visualise the bases which must have been set up, perhaps approaching the Thule standard, at Rudolf Island, Severnaya Zemlya, and probably at Wrangel Island too, the last being a territory in which Britain relinquished her claim in a moment of Arctic disinterestedness by Disraeli.

Whether for peace or for war, Russia is going to play an increasingly important role in future world air strategy. If it be for peace, then the Russian Arctic will form the link between London and Tokio, with the possibility of an intermediate landing on the Yenisei, where the Russians are developing industry on a large scale. If it be for war, the Arctic would form a common frontier between the British Isles and the American continent on the one hand, and Arctic Russia on the other. The need for lateral communications on such a vast front requires no emphasis.

The map which accompanies this article is designed to show, on an azimuthal equidistant projection, how the northern countries lie around the Polar Basin and why great savings in distance may be effected by traversing the Arctic, instead of using the more southerly routes at present current. London has been chosen as the centre, although a few hundred miles could obviously be clipped off all the routes shown by hinging them on Prestwick.

While the political outlook in Russia remains uncertain, and the economical advantages of running an airline to Tokio may be doubtful under conditions prevailing at this very moment, Winnipeg and Vancouver, particularly the latter, can be considered as the basis of a shorter term policy. An aircraft would have to cruise at only 300 m.p.h. in order to connect London with the Pacific coast of America in a matter of sixteen hours: double the speed and half the time are possibilities of the foreseeable future. In view of the westward trend of industry in North America, the economical advantages of such speedy contact with the West Coast will increase during the next few years. Additionally this would open up the possibility of an alternative route to Australia and New Zealand by way of the Pacific Islands.

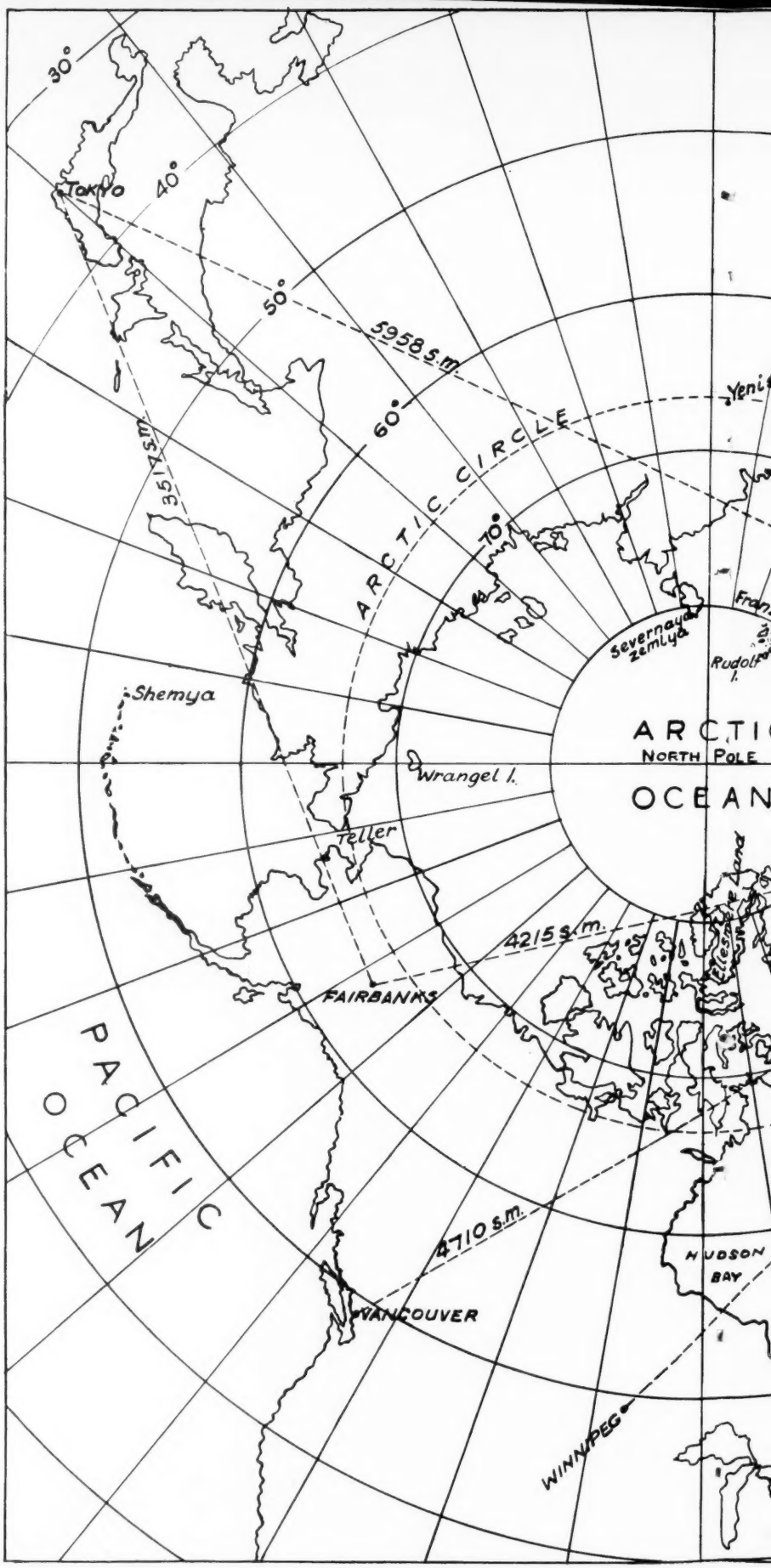
The Arctic Milestone of S.A.S.

That these proposals are not outside the bounds of technical achievement at the present time has been proved in a striking way by S.A.S., the Scandinavian Airline Company. In November 1952, when the North Polar regions were clad in continual darkness, S.A.S. sent off their first DC-6B, commanded by the famous Danish Captain Povl Jensen with a crew of eleven, on its delivery flight from the makers in Los Angeles to the new owners in Copenhagen. This was more than an ordinary delivery flight, for 24 passengers were on board and the route chosen lay *via* Edmonton (1,676 nautical miles), Thule (1,696 nautical miles) to Copenhagen (2,082 nautical miles). They flew within 150 miles of the Northern Magnetic Pole. The proving flight, accomplished in $24\frac{1}{2}$ hours flying time, was no mere flash in the pan, for S.A.S. proceeded to announce their intention of establishing a trans-Arctic airline to West America and to Japan.

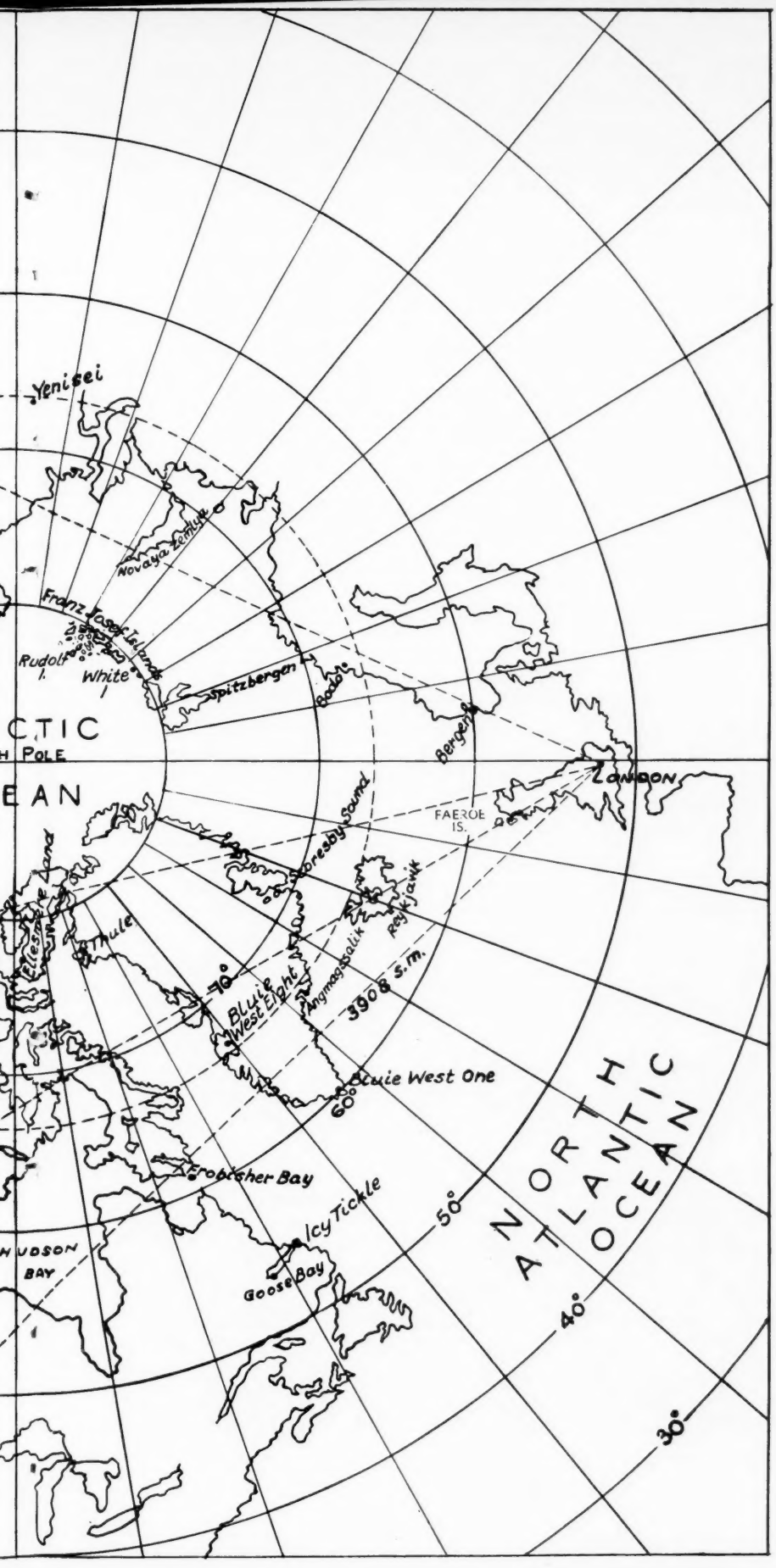
Within a month a second aircraft had left Los Angeles and this one deviated at Thule to Sondre Stromfiord (Bluie West Eight) on the West Coast of Greenland, where it landed in order to examine the facilities available there. Sondre Stromfiord is a valley site, first surveyed by the Watkins' Expedition of 1931. Topographically and from the point of view of radio facilities, it is inferior to Thule and unsuitable for all-the-year operations. Thence the DC-6B flew direct to Stockholm. In May 1953 another S.A.S. DC-6B made the first flight from Scandinavia to Japan, a performance repeated almost exactly a year later. The route was: Bodo—Fairbanks (2,840 nautical miles), Fairbanks—Shemya (Aleutians) (1,513 nautical miles), and Shemya—Tokio (1,775 nautical miles).

Special Equipment for Arctic Aviation

The special navigational problems of these flights arise mainly from the behaviour of the compass within



Disposition of the Northern Countries around the Polar Basin, showing distances for various air routes from London.



This map is an azimuthal equidistant projection.

(*Courtesy of the Royal Geographical Society*)

600 miles of the Magnetic Pole. In this area the earth's horizontal component is so weak and the variation so great that the magnetic compass cannot be relied upon. To meet the need of navigating in this dead area, Bendix have produced a special low precession gyro called the Polarpath. The procedure for steering by the Bendix Polarpath gyro is to check the heading of the aircraft at regular half-hourly intervals by astro compass and compare the actual heading with the reading on the Polarpath gyro. The difference is plotted on the gyro graph, which therefore gives the rate of precession between the readings. If the heading of the aircraft reads more than the gyro, then the drift is to starboard and *vice-versa*. Once the rate of precession has been established, this can be used for calculating new headings.

As a result of their first trans-Polar flights, S.A.S. suggested that latitude integration should be introduced into the Polarpath gyro system. Now this has been added, the navigator is able to set the gyro to nil degrees drift at any latitude and eliminate the drift caused by the earth's rotation. Only random drift is left and this never exceeds one degree per hour. The latitude integration unit also enables the navigator to fly a rhumbline track on the gyro by making a special correction in addition to that for latitude.

S.A.S. have been using their latest development of the Polarpath gyro not only for all recent trans-Polar flights, but also on the more conventional trans-Atlantic runs, where they believe it will prove the right answer to the problem of navigation at jet-transport speed.

The other unusual requirement for Polar flying is in maps. The rapid convergence of the meridians of longitude near the Pole makes their use unsatisfactory, and so, while the ordinary Mercator Charts hold good up to 65°N, above this a transverse grid is used on Lambert Conformal Conical Charts. Grid North is the same as True North from Greenwich continued along the 180° meridian.

Political and Security Obstacles

These well organised and impressive preliminary flights of S.A.S., which had heralded a new era in Arctic aviation, were gradually leading to the establishment of a regular airline. But the obstacles of this have proved slow to yield. From the point of view of political clearance, agreements had to be obtained from Denmark

(Courtesy of Scandinavian Airlines System)

Greenland's mountains, so impenetrable from below, become just scenery for Arctic air lines.

(for Greenland), Canada, U.S. and Japan. The U.S. Authorities did not at first wish the service to terminate at Los Angeles (which only saves 250 miles compared with the Chicago-New York route) but at Seattle, where the saving would be over 1,200 miles. The U.S.A.A.F. did not, and still does not, agree to the use by regular Civil Airlines of Thule, so Sondre Stromfiord is the nearest permitted alternative as an intermediate landing place. Therefore the Scandinavian—U.S. route will have to run Copenhagen—Sondre Stromfiord—Edmonton*—Seattle, and the Japanese one Copenhagen—Bodo—Fairbanks—Shemya—Tokio. The U.S. Government have eventually conceded to S.A.S. the right to run right through to Los Angeles. On this Polar route the normal complement in the DC-6B's will be 9 crew and 48 passengers.

The First Arctic Air Line in the World

15th November 1954 was the day of triumph for S.A.S., the day which crowned all their months of planning with a signal success. If spirits ever stir, then surely on that day must the host of departed pioneers—Andrée, Amundsen, Nobile, Gino Watkins and Levanevsky—have raised their glasses high to drink, "God speed to the first Arctic Air Line in the World." From Los Angeles the *Royal Viking* headed Eastbound to the Arctic and from Copenhagen the *Helge Viking*, carrying the Prime Ministers of Norway, Sweden and Denmark, flew west. One hundred miles East of Greenland the two pioneer services passed each other in bright moonlight, to the accompaniment of the green and red flashes of the aurora borealis. Both flights were completely uneventful and the elapsed time in each case was just over 24 hours. May this be a happy augury for many thousands of safe and uneventful Arctic flights.

Canada's Contribution to Arctic Flying

Although our Canadian cousins have not hitherto appeared in the picture of long-distance Polar flying, they have nevertheless made great contributions to Arctic aviation in operations peculiarly suited to the needs of their vast Northern Territories. Mining settlements, oilfields and trapping stations have led to the perfection of Arctic bush-flying in Canada with seaplanes, skiplanes, amphibians and landplanes. While much of these operations are done by private individuals and charter companies, regular air lines have spun their mesh over the Arctic, as is evidenced by the regular services of Canadian Pacific Airlines to Aklavik. The first Comet to be flown across the Atlantic, too, was taken *via* Iceland by the Royal Canadian Air Force.

That Canada has no intention of being satisfied with internal Arctic Airways, or of being a mere staging post for other nations, was strikingly indicated in September 1954. Then Canadian Pacific Airlines filed an application for permission to run from Vancouver to Amsterdam *via* Sondre Stromfiord. The reason Amsterdam was suggested as the European terminal was because the Canadians give regular traffic rights to the Dutch at Montreal, and wished to utilise the reciprocal provision in the agreement.

Britain's Backwardness in the Arctic

Seeing the progress which the Scandinavians have achieved in pioneering Arctic aviation, we in this country may well reflect with humility upon our standing in the matter. True, the Royal Air Force has done some splendid scientific work in the Arctic since the war, but what has happened to our Civil Ensign? There has been no question even of civil aviation observers being attached to the R.A.F. to study Arctic flying. Both our Ministry of Civil Aviation and B.O.A.C. seem too preoccupied with other things to spare a second for the Arctic. But the problem is pressing. If one line can fly from Copenhagen to Tokio by the Arctic, reaping all the prestige of pioneering a new and shorter route, then surely another should be able to operate between London and Tokio across the top of the world, thus knocking more than 2,000 miles off the distance of the present B.O.A.C. route.

Canadian and British Partnership the Answer

In the Arctic lies a field of great opportunity for Britain and for Canada. On the one hand, speedy long-distance communications with the outside world are vital to the economic survival of the inhabitants of this island: on the other, the development of her Arctic territories is vital to the future of Canada. Not only our needs are complimentary but also our means; the Old Country has unrivalled experience in the running of long-distance air lines and no one knows better than Canada how to operate aircraft in Arctic conditions.

Others have already answered Andrée's challenge. "How soon, I wonder, shall we have successors? Shall we be thought mad or will our example be followed?" History will never judge Andrée mad for pointing the path which others should follow: but should those who have been shown the way refuse to follow it, they may indeed receive a less kind judgment.

ACKNOWLEDGMENTS

The author is especially indebted to Mr. K. Hagerup-Svenden for technical details concerning the S.A.S. flights. The author and the Editor wish to thank all those who have helped with the illustrations, particularly the Scott Polar Research Institute, the American Geographical Society, the National Geographic Society, the Royal Geographical Society and S.A.S.

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*Because the runways at Edmonton had not been lengthened in time, the initial services had to be routed through Winnipeg, resulting in a Los Angeles-Copenhagen nautical mileage of 5,160.

Theory of Wrinkling in Sandwich Construction

by

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SUMMARY: In this paper a theory of wrinkling in Sandwich Construction is presented in two parts. In the first part, the thickness of the core is regarded as finite. The wrinkling stress is given by a simple square root formula consisting of the Young's moduli of the materials and the ratio of the thickness of the face and core. In the second part of the theory the same procedure is followed, with the main difference that shearing stresses in the core are also considered, and the analysis is extended to the case where the face is supported by a sufficiently thick or a semi-infinite medium. The result for the wrinkling stress is a cubic root formula which consists of the moduli of the materials but indirectly depends upon the geometry of the structure; this formula is valid only if the ratio of the thickness of the core and the face is greater than or at least equal to the ratio of the width of the marginal zone of distortions in the core, and the thickness of the face. The width of the zone is also useful as the criterion which discriminates between the two cases of buckling as envisaged in this paper. The theory is compared with the previous works, and also with the test results already available. The selection of the experimental data comprises steel, aluminium alloy and Papreg (laminated paper plastic) as the face; and onazote, cellular cellulose acetate, granulated cork, sponge rubber and expanded formvar as the core materials over a wide range of core-face thickness ratio. The agreement between the theory and the tests is satisfactory.

1. Introduction

The face buckling of a sandwich strut or panel loaded in compression is known as wrinkling, or sometimes referred to as a ripple or crinkling type of instability. A considerable amount of theoretical work has been done, and a great deal of experimental data on this subject is now available. Many authors[1, 3, 4, 6] have obtained simple formulae for the wrinkling stress covering both homogeneous (isotropic) and grained (aelotropic) cores. However it is found that the experimental values of this stress scatter over a wide range. Some of this discrepancy may be due to imperfections in the face, such as initial waviness, and some is attributed to the non-uniformity in core materials.

The treatment of the subject has been more or less similar. Gough, Elam, and de Bruyne[1] have considered several combinations of skin and supporting medium. The case of an isotropic semi-infinite medium with complete adhesion with the skin yields a simple formula. The investigation by Hoff and Mautner[3] is based on the assumptions that the displacement in the core occurs only in the marginal zones adjacent to the faces, and they diminish linearly to zero when full depth of the zone is reached. Williams[6] considered the core as one in which the distortions decrease exponentially and finally become almost zero as the central plane of the core is reached.

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The formulae for wrinkling stress thus obtained are independent of the geometric configuration of the sandwich structure, but are functions of the moduli of the materials of the facing and the core.

It is obvious that the core must be sufficently thick so that the above assumptions may be strictly true. As is shown later, it is clear that in many cases where failure is attributed to wrinkling, the core must be regarded as finite and the distortions extended to the entire core.

Gough, Elam, and de Bruyne[1] have considered several cases in which the medium has a finite thickness. The result has been presented graphically, as the calculations became rather cumbersome and the buckling stress could not be expressed by a simple formula. The curves for the case of two equally loaded faces separated by a core of finite thickness do not represent accurately the actual conditions encountered in sandwich constructions, since the antisymmetric type of deformation assumed in the theory has not been observed in experiments.

Therefore it is thought that a further study of the failure of sandwich construction due to wrinkling is necessary. In the present investigation of this phenomenon, the case of a skin supported by a core of finite thickness is considered first. Then the method adopted is applied for further study of the case where the core is sufficiently thick to justify the assumptions which restrict its distortions to its outer regions or where it can be treated as semi-infinite.

Notation

- A amplitude of sinusoidal displacement
- b thickness of the core
- E_c Young's modulus of the core in the transverse direction (y-)
- E_f Young's modulus of the face
- E_l Young's modulus of the core in the longitudinal direction (x-); parallel to the load
- G_c shear modulus of the core in the plane xy
- I moment of inertia of the face of unit width
- k modulus of foundation or spring constant
- k_w wrinkling coefficient
- l one-half of the wave length of wrinkling
- p load in face per unit width
- t thickness of the face
- W width of the marginal zone
- ε normal strain
- γ shear strain
- σ_{cr} wrinkling stress
- λ wave length of wrinkling
- ω displacement
- ν Poisson's ratio

PART I

Face Separated by Core of Finite Thickness

For a given dimension of the sandwich structure, if the core is sufficiently thin, the failure under compressive end load may occur by the over-all bowing of the structure similar to Euler buckling, but if the thickness is such that this kind of failure is not likely to occur, then the sandwich face would buckle in short waves. The buckling is supposed to take place as shown in Fig. 1, where ripples, symmetric with respect to the central plane of the core, appear in both the skins. This type of failure involves the bending of the skins and the compression or elongation of the core fibres in directions perpendicular to the central plane, these fibres behaving like independent springs fixed to this plane with no shearing stresses between them. The buckling distortion in the core parallel to the direction of loading is considered small when compared with those in the transverse direction. As the wave length of the wrinkle is generally small, the supports at the edges are assumed to have no effect and the buckling of the skin would be exactly the same as if it was infinitely long. Thus the wrinkling of the sandwich face may be regarded as the buckling of the beam attached to a fixed base (central plane) by means of vertical fibres which act as individual springs. Because of the symmetry only one half of the sandwich is considered.

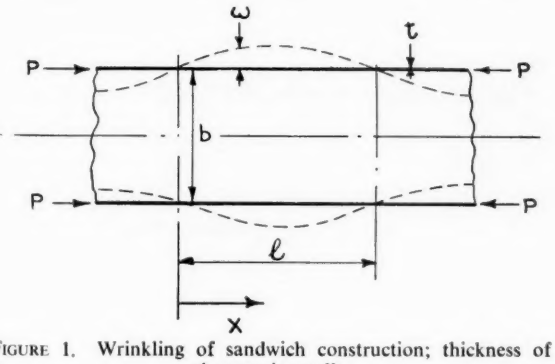

FIGURE 1. Wrinkling of sandwich construction; thickness of the core is small.

The modulus of foundation corresponding to one-half of the core is

$$k=\frac{2E_c}{b} \quad . \quad . \quad . \quad . \quad (1)$$

where k is expressed in pounds per square inch per inch of deflection, E_c is the Young's modulus of the core in a direction perpendicular to the face, and b is the thickness of the core. The differential equation of the buckling of the beam which is elastically supported and subjected to the axial force p is given by[9]

$$\frac{d^4\omega}{dx^4}+\frac{p}{EI}\frac{d^2\omega}{dx^2}+\frac{k\omega}{EI}=0 \quad . \quad (2)$$

Since we are interested in the periodic solution of this equation, the beam (skin) may be assumed to buckle in sine waves and the deflection is given by

$$\omega=A\sin\frac{\pi x}{l} \quad . \quad . \quad . \quad (3)$$

Substituting (3) in (2), and writing E_f for E, we have

$$\frac{\pi^4}{l^4}-\frac{p}{E_fI}\frac{\pi^2}{l^2}+\frac{k}{E_fI}=0 \quad . \quad . \quad (4)$$

or

$$p=E_fI\frac{\pi^2}{l^2}+\frac{kl^2}{\pi^2} \quad . \quad . \quad . \quad (5)$$

The minimum value of p can be obtained by differentiating (5) with respect to l and putting $dp/dl=0$.

Therefore

$$\frac{dp}{dl}=-2E_fI\frac{\pi^2}{l^3}+\frac{2kl}{\pi^2}=0 \quad . \quad . \quad (6)$$

The critical half-wave length corresponding to the smallest axial load is obtained from (6) and is given by

$$l_{cr}=\pi(E_fI/k)^{\frac{1}{4}} \quad . \quad . \quad . \quad (7)$$

Substituting (7) in (5), we have for minimum axial load

$$p_{min}=2(E_fIk)^{\frac{1}{2}} \quad . \quad . \quad . \quad (8)$$

For skin of thickness t and of unit width, the moment of inertia is

$$I=\frac{t^3}{12} \quad . \quad . \quad . \quad . \quad (9)$$

Substituting (1) and (9) in (7), the critical wave length of wrinkling in sandwich construction is given by

$$\lambda=2l_{cr}=2\pi t\left[\tfrac{2}{3}(E_f/E_c)(b/t)\right]^{\frac{1}{2}} \quad . \quad (10)$$

and the critical load is

$$p_{min}=t(\tfrac{2}{3}E_fE_c\,t/b)^{\frac{1}{2}} \quad . \quad . \quad . \quad (11)$$

and the wrinkling stress is

$$\sigma_{cr}=(\tfrac{2}{3}E_fE_c\,t/b)^{\frac{1}{2}} \quad . \quad . \quad . \quad (12)$$

This result is applicable to both isotropic and grained materials. It may be seen that Young's modulus for the core in the direction perpendicular to the face is important in this case and is in agreement with the present day practice of using the grained materials as the core so as to have the direction of larger Young's modulus orientated perpendicular to the faces.

Nothing is contained in this theory to suggest when a given structure has to be treated as having the core of finite thickness, and when the result given by the formulae (10) and (12) may be applied. It is certainly necessary and desirable to have this information, otherwise the designer would be at a disadvantage in handling and proportioning the dimensions of the structure. The required information, however, is made available in Part II of the analysis.

PART II

Face Supported by a Sufficiently Thick Core

The investigation presented in this section is similar to that of Part I except that now the shearing stresses in the core are also considered. The faces are again treated as beams supported on an elastic foundation. Unlike the first part of the analysis, in this case the modulus of foundation cannot be determined straight away, because shearing stresses are present in the core. However it could be easily evaluated by the requirement that the strain energy stored in the equivalent spring for a given wave length of buckling, must be equal to the strain energy stored in the core corresponding to the same wave length.

It is now assumed that the displacements in the core are restricted to the marginal zone of width W adjacent to the faces. They consist of elongation or compression of the transverse fibres and deformation due to shear in their planes. These displacements are maximum at the common surface of the core with the face and decrease linearly until they finally become zero when the full depth W is reached, the width of the zone being less than or equal to one-half of the thickness of the core. It is assumed that the shear in the core is responsible for this phenomenon. It is further assumed that the longitudinal displacement of the core at buckling is small and can be ignored. The buckling pattern is again regarded as symmetrical as is shown in Fig. 2.

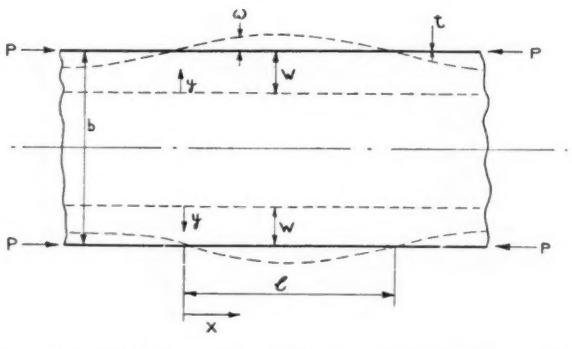

FIGURE 2. Wrinkling of sandwich construction; thickness of the core is large.

The transverse displacement (y-direction) of the core at the point originally at (x, y) is given by

$$\omega = A\,(y/W)\sin \pi x/l \quad . \quad . \quad (13)$$

the normal strain in the core is

$$\varepsilon_y = \frac{\partial \omega}{\partial y} = (A/W)\sin \pi x/l \quad . \quad . \quad (14)$$

Because of the symmetry, only one-half of the cross section of the core need be considered. The extensional strain energy within one-half of the wave length is thus

$$U_\varepsilon = (E_c/2)\int_0^l \int_0^W \varepsilon_y^2\, dxdy$$

$$= (A^2/4)\,E_c l/W \quad . \quad . \quad . \quad (15)$$

where E_c is the Young's modulus of the core in the direction normal to the surface $(y-)$.

The shear strain in the core is

$$\gamma = \frac{\partial \omega}{\partial x} = \frac{A\pi}{l}\left(\frac{y}{W}\right)\cos\frac{\pi x}{l} \quad . \quad . \quad (16)$$

The shear strain energy in the core stored within one-half of wave length is

$$U_\gamma = (G_c/2)\int_0^l \int_0^W \gamma^2 dxdy$$

$$= (A^2/12)\,\pi^2 G_c \frac{W}{l} \quad . \quad . \quad . \quad (17)$$

where G_c is the shear modulus of the core corresponding to the longitudinal and the transverse plane (xy). If the core is replaced by an equivalent spring of constant k at $y = W$ the energy stored for displacement ω is

$$U_s = \tfrac{1}{2}\int_0^l k\omega^2 dx \quad . \quad . \quad . \quad (18)$$

where

$$\omega = A\sin\frac{\pi x}{l} \quad . \quad . \quad . \quad (19)$$

Substituting (19) in (18), we have

$$U_s = \tfrac{1}{2}kA^2\int_0^l \sin^2\frac{\pi x}{l}\, dx$$

$$= \frac{A^2}{4}kl \quad . \quad . \quad . \quad . \quad (20)$$

The strain energy stored in the springs must be equal to the sum of the extensional and shear strain energies stored in the core.

Therefore

$$U_s = U_\varepsilon + U_\gamma \quad . \quad . \quad . \quad (21)$$

substituting the corresponding values (21) becomes

$$\frac{A^2}{4}kl = \frac{A^2}{4}\frac{E_c l}{W} + \frac{A^2}{12}\pi^2 G_c \frac{W}{l} \quad . \quad (22)$$

solving for k, we have

$$k = \frac{E_c}{W} + \frac{\pi^2}{3}G_c\frac{W}{l^2} \quad . \quad . \quad . \quad (23)$$

The actual value of W is that which makes k a minimum. Consequently dk/dW must vanish.
Therefore

$$\frac{dk}{dW} = -\frac{E_c}{W^2} + \frac{\pi^2}{3}\frac{G_c}{l^2} = 0 \quad . \quad (24)$$

or

$$\left(\frac{l}{W}\right)^2 = \frac{\pi^2 G_c}{3E_c} \quad . \quad . \quad . \quad (25)$$

Substituting (25) in (23) we have

$$k = \frac{2E_c}{W} = \tfrac{2}{3}\pi^2 G_c \frac{W}{l^2} \quad . \quad . \quad (26)$$

Having thus obtained the value of the spring constant or modulus of foundation, the problem is very much simplified and now it only remains to solve for the critical load, and the wave length by means of the equations (8) and (7).

For the sake of convenience all the important equations which are required in the determination of the required quantities are rewritten:—

$$k = \frac{2E_c}{W} = \tfrac{2}{3}\pi^2 G_c \frac{W}{l^2} \quad . \quad . \quad (i)$$

$$\left(\frac{l}{W}\right)^2 = \frac{\pi^2 G_c}{3E_c} \quad . \quad . \quad . \quad (ii)$$

$$l_{cr} = \pi (E_f I/k)^{\frac{1}{3}} . \quad . \quad . \quad . \quad (iii)$$

$$p_{min} = 2 (E_f I k)^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad (iv)$$

We have now four quantities involving four unknowns namely k, l, W and p. The solution of these equations finally yields the following result.

$$kt = 2{\cdot}773 \left[\frac{(E_c G_c)^2}{E_f}\right]^{1/3} \quad . \quad . \quad (27)$$

$$W/t = 0{\cdot}721 \, [E_f E_c / G_c^2]^{1/3} \quad . \quad . \quad (28)$$

the critical wave length is given by

$$\lambda/t = 2l/t = 2{\cdot}614 \, [E_f^2/(E_c G_c)]^{1/6} \quad . \quad (29)$$

and finally the critical stress

$$\sigma_{cr} = 0{\cdot}961 \, (E_f E_c G_c))^{1/3} . \quad . \quad . \quad (30)$$

It may be seen that this analysis is applicable to isotropic as well as core materials having different Young's moduli in longitudinal and transverse directions with shear modulus unrelated to either. Here it may be of interest to note that the results previously obtained[3, 6] for the critical stress, if the core is regarded as sufficiently thick, are similar and expressed as

$$\sigma_{cr} = k_w (E_f E_c G_c)^{1/3} \quad . \quad . \quad (31)$$

where k_w may be called the wrinkling coefficient and equal to 0·91 and 0·85 respectively in the investigations carried out by Hoff and Mautner[3] and Williams[6].

If the formula

$$\sigma_{cr} = (E_f E_c^2)^{1/3} \, [3/\{2(1+\nu)(3-\nu)\}]^{2/3} \quad . \quad (32)$$

TABLE I

FACE: STEEL, $E_f = 30 \times 10^6$ lb./in.^{2} CORE: ONAZOTE. POISSON'S RATIO = 0·3.
THICKNESS OF THE CORE $b = 0{\cdot}5$ in.

t in.	b/t	E_c lb./in.^{2}	W/t*	Critical wave length			Wrinkling stress		
				Present theory in.	Ref. 1		Present theory lb./in.^{2}	Ref. 1	
					Test in.	Theory in.		Test lb./in.^{2}	Theory lb./in.^{2}
0·01	50	356	82·9	1·285	—	1·27	11,900	10,500	13,850
0·01	50	356	82·9	1·285	—	1·27	11,900	15,000	13,850
0·015	33⅓	356	82·9	1·714	1·9 1·8	1·77	14,600	19,000	15,600
0·02	25	356	82·9	2·16	2·4	2·19	16,900	21,200	17,300
0·01	50	675	67·0	1·095	1·5	1·1	16,400	18,500	20,100
0·01	50	675	67·0	1·095	—	1·1	16,400	14,000	20,500
0·015	33⅓	675	67·0	1·485	—	1·5	20,130	20,900	20,100
0·02	25	1,135	61·3	1·617	—	1·64	30,100	24,500	32,600
0·015	33⅓	1,410	52·4	1·235	—	1·65	29,100	25,350	37,800
0·02	25	1,410	52·4	1·53	1·5	1·56	33,600	24,000	37,800
0·01	50	2,575	42·9	0·78	—	0·75	32,100	38,000	33,200
0·015	33⅓	2,575	42·9	1·063	0·9	1·09	39,300	45,000	49,500
0·02	25	2,575	42·9	1·318	1·4	1·35	45,060	57,000	52,000
0·01	50	2,580	42·4	0·78	0·6	0·75	32,100	36,400	33,200
0·01	50	2,580	42·4	0·78	0·8	0·75	32,100	42,500	33,200
0·01	50	2,580	42·4	0·78	—	0·75	32,500	37,000	33,200
0·015	33⅓	2,580	42·4	1·063	0·9	1·09	39,300	53,900	49,500
0·015	33⅓	2,580	42·4	1·063	1·0	1·09	39,300	58,000	49,000
0·020	25	2,580	42·4	1·318	—	1·35	45,060	66,140	52,000
0·015	33⅓	3,250	39·8	1·002	0·9	1·00	44,160	49,300	60,700
0·02	25	3,325	39·8	1·237	1·5	1·25	51,600	44,000	60,700

* Here $W/t = (E_f E_c / G_c^2)^{1/3}$

obtained by Gough, Elam and de Bruyne[1] for a semi-infinite medium is expressed in the same form as (31), with Poisson's ratio $\nu = 0{\cdot}3$ and $G_c = E_c/[2(1+\nu)]$ it gives $k_w = 0{\cdot}78$.

It is thus seen that the previous results differ from the present formula by an amount equal to 5·2 per cent., 11·5 per cent. and 18 per cent. respectively. As is shown later (Fig. 4) it is obvious that the coefficient $k_w = 0{\cdot}961$ obtained in the present analysis, is in close agreement with the tests.

The information to which reference was made earlier, and which is required to enable the designer to know beforehand when the result derived in the first part of the theory should be applied, is now obtained from the fact that one-half of the thickness of the core must be greater than, or at least equal to, the proposed width W as given by (28) so that the core be regarded as sufficiently thick or more or less semi-infinite. If this condition is not satisfied the assumptions made in this section are not satisfied completely. Therefore in such cases the result obtained in Part I theory should be used to predict the failure. It appears then, that when $b/2 = W$ a transition would take place from one type of behaviour to the other. As this change cannot occur suddenly, it is reasonable to suggest that the critical stress, at this equality and possibly in its neighbourhood, is taken as the average of the two cases. In equation (12) if we put

$$b = 2W = 1{\cdot}442t\,(E_f E_c / G_c^2)^{1/3} \quad . \quad (33)$$

we have $$\sigma_{cr} = 0{\cdot}68\,(E_f E_c G_c)^{1/3}. \quad . \quad . \quad . \quad (34)$$

Averaging this with (30) the critical stress at the transition can be taken as

$$\sigma_{cr} = 0{\cdot}82\,(E_f E_c G_c)^{1/3}. \quad . \quad . \quad . \quad (35)$$

Comparison of the Theory with Experiment

To compare the present theory with the tests, the experimental data already available is largely used. Here it may be of interest to note that most of the combinations of the skins and stablising medium treated by Gough, Elam and de Bruyne[1] belong to one or other of the cases considered in this paper. Since their arrangement IIb or IIa ("supporting medium of finite thickness with rigid back") had been fully investigated experimentally and a good agreement between the predicted and observed wave length was shown, it is also considered here in detail In the test, sheet of spring steel as a face and onazote with Young's modulus varying from 356-3,325 lb./in.^{2} as core, was used. For all the specimens given in Table II of Ref. 1, the condition $b/2 < W$ is satisfied*. Therefore calculations have to be made by means of the theory given in Part I. The estimated values together with the Table II of Ref. 1 are given in Table I for comparison. It may be seen that the calculated wave lengths agree very well with the observed and differ very little from the predicted values of Ref. 1. The equation (10) is plotted non-dimensionally in Fig. 3 and observed wave lengths are noted.

In the tests carried out by Hoff and Mautner[3] two types of buckling were observed. One was symmetrical and the other was designated as a skew ripple. Altogether 51 panels were tested with Papreg (high strength laminated paper plastic) as a face material and compression moulded cellular cellulose acetate as the core. There is a considerable scatter in the result mainly due

*Since the face was supported on both the sides, E was replaced by $2E$ and in the present case $2k$ for k and $2W$ for W must be used.

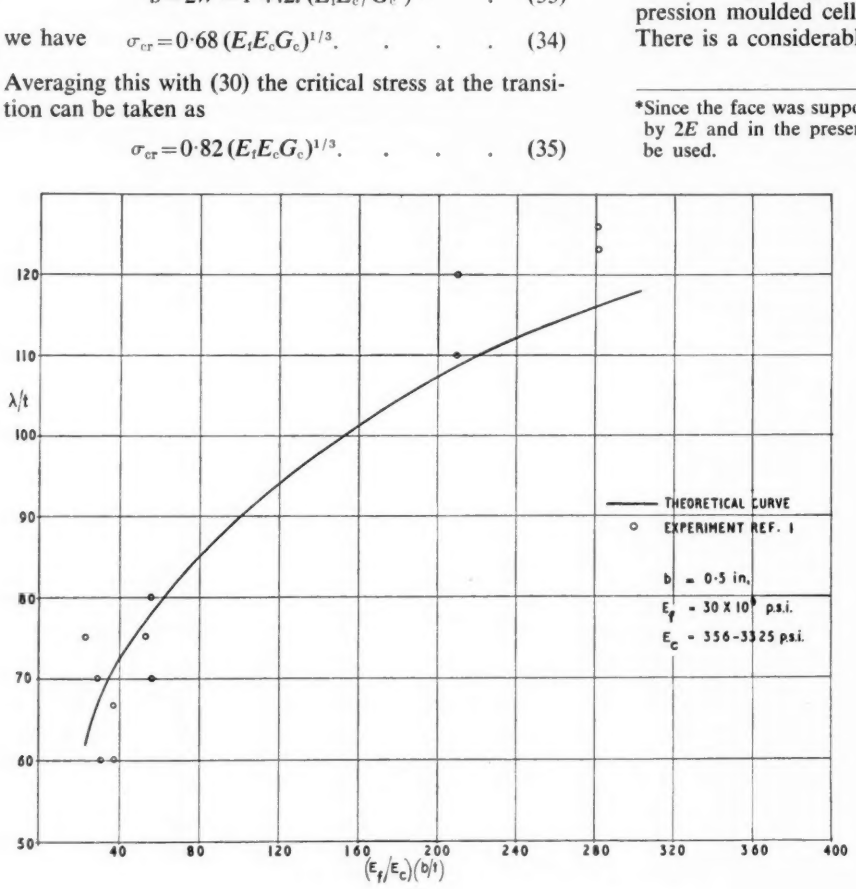

FIGURE 3. Wave length of wrinkles. Face: Steel. Core: Onazote (expanded ebonite).

TABLE II

FACE: PAPREG, $E_f = 3 \times 10^6$ lb./in.^{2}
CORE: CELLULAR CELLULOSE ACETATE
$E_c = 1{,}500$ lb./in.^{2} $G_c = 750$ lb./in.^{2} $2W/t = 28{\cdot}8$

No. of specimen	t in.	b in.	b/t	Width of panels in.	Wrinkling stress: Theory lb./in.^{2}	Wrinkling stress: Test Ref. 3 lb./in.^{2}
19	0·01125	0·248	22·05	4	11,170	11,110
20	0·01125	0·239	21·25	4	11,880	12,230
21	0·01125	0·207	18·40	4	12,770	4,560
44	0·02025	0·441	21·75	4	11,740	13,830
45	0·02025	0·434	21·40	4	11,840	13,700
46	0·02025	0·443	21·85	4	11,720	12,590
47	0·02025	0·452	22·30	4	11,600	12,710
40	0·01575	0·457	29·00	4	10,170	9,930
41	0·01575	0·465	29·50	4	10,080	11,300
42	0·01575	0·456	28·95	4	10,180	10,480
43	0·01575	0·467	29·65	4	10,060	10,290

to the uncertainty of the properties of the materials used or to the non-uniformity of the core. However with $E_f = 3 \times 10^6$ lb./in.^{2}, $E_c = 1{,}500$ lb./in.^{2} and $G_c = 750$ lb./in.^{2}, critical stress for the panels the core thickness of which has to be regarded as finite agrees very well with the formula (12). The values are given in Table II.

However the panels with very small core-face thickness ratio (b/t) and which failed according to skew pattern do not come under this category. There is reason to believe that these panels, due to inadequate edge support and core thickness, failed in Euler fashion involving a wave length of the order of twice the width of the panels, in which case the failing load per unit width of these panels can be given generally by $p = \pi^2 EI/l^2$ where $I = (l/2)\,t\,(b+t)^2$ and l is equal to the width of the panel. If this point of view is applied, the prediction regarding the type of failure, either symmetric or quasi-Euler, would be in agreement for 50 out of 51 panels tested, and in addition failing loads calculated in this way would also agree with the observed critical loads.

In Table III more examples of failures pertaining to theories proposed in Parts I and II are given.

Lastly the test result obtained by Barwell and Riddell[5] is utilised to compare with the theory given in Part II, since all the specimens tested by them belong to this case. The core used is the expanded formvar with $E_c = 1{,}800$ lb./in.^{2}, $E_1 = 22{,}000$ lb/in.^{2} and $G_c = 2{,}800$ lb./in.^{2} and the face material is steel with ratio b/t varying from 50 to 250. They also applied a correction for the increase of flexural rigidity of the face due to the layer of adhesion. Therefore in this sense the test may be considered to be more accurate so far as relatively very thin faces are concerned. The calculated and the corrected observed values of the critical load are given in Table IV and in Fig. 4. It may be seen that the agreement between the theory and test is satisfactory.

Conclusion

From the comparison of the theory with the tests, it is clear that before proceeding to evaluate the wrinkling stress in sandwich construction it is essential to know the ratio W/t.

If the width of the zone of core distortion is greater than half the thickness of the core, then the wrinkling stress is given by the square root formula, and if it is less than half the thickness of the core, then the wrinkling stress is given by the cubic root formula. At the equality ($2w = b$) the average of the stresses obtained by the two formulae appears reasonable.

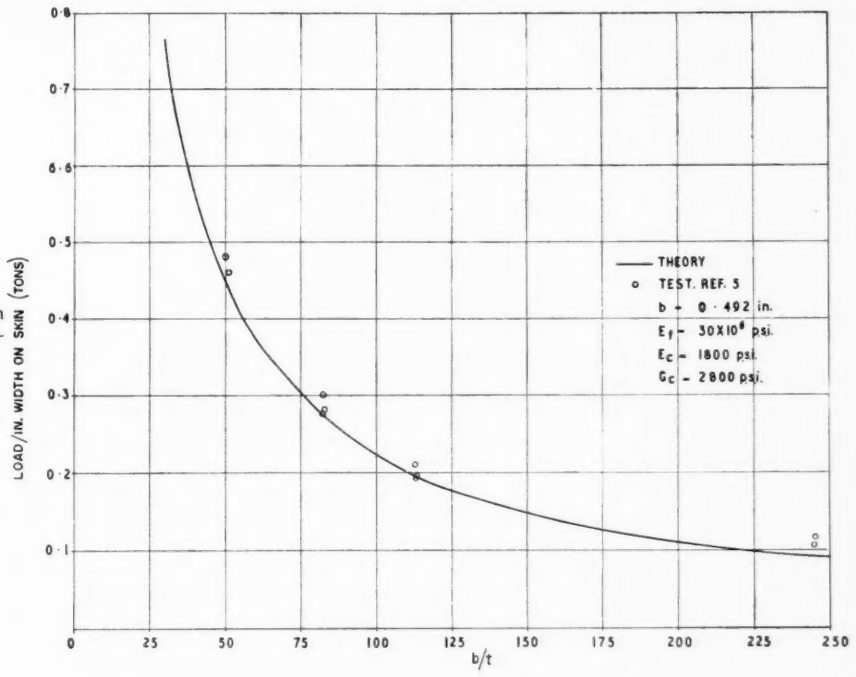

FIGURE 4. Wrinkling of sandwich strut. Face: Steel. Core: Formvar (expanded rubber).

TABLE III

FACE: ALUMINIUM ALLOY, $E_f = 10^7$

Core	t in.	b in.	b/t	E_c lb./in.²	G_c lb./in.²	$2W/t$	Wrinkling Stress: Theory lb./in.²	Wrinkling Stress: Test from Ref. lb./in.²
Granulated cork core sp. gravity equals 0·35 $E_1 = 1{,}180$ lb./in.²	0·0196	1·0	57·3	520	330	52·4	9,760	9,760 Ref. 8
	0·012	0·75	63·2	520	330	63·2	11,410	11,210 Ref. 8
	0·012	1·0	84·1	520	330	84·1	11,410	10,920 Ref. 8
	0·0082	0·437	53·4	900	310	65·5	10,600	10,130 Ref. 7
		0·874	107	2,400	590	58·1	23,250	17,100 Ref. 7
		1·25	152	2,500	500	66·9	22,300	19,040 Ref. 7
		1·625	198	1,400	400	64·0	17,060	18,840 Ref. 7
		2·000	244	1,200	250	83·2	13,860	14,370 Ref. 7

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TABLE IV

FACE: STEEL, $E_f = 30 \times 10^6$

CORE: EXPANDED FORMVAR; $E_1 = 22{,}000$ lb./in.²; $E_c = 1{,}800$ lb./in.²; $G_c = 2{,}800$ lb./in.²; $b = 0{\cdot}492$ in.; $W/t = 11{\cdot}68$

No. of specimen	Thickness of skin	b/t	Failing load in tons/in. width of the skin: Theory	Ref. 5 Test
1	0·002	246	0·0915	0·117
2	0·002	246	0·0915	0·108
3	0·00434	113·3	0·199	0·210
4	0·00435	113·0	0·199	0·198
5	0·00434	113·3	0·199	0·195
6	0·00593	83·0	0·271	0·278
7	0·00596	82·6	0·273	0·274
8	0·00597	82·4	0·273	0·300
9	0·00977	50·4	0·447	0·482
10	0·00971	50·6	0·444	0·460

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The Aerodynamic and Aeroelastic Characteristics of the Crescent Wing

by

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1. Introduction

It would be possible to write a paper conforming, literally, to the above title in very few words by simply describing the behaviour of the crescent wing in various circumstances. Such treatment, however, would avoid what is really the prime question of all, namely, why is the crescent wing used? What is the attraction of this layout? The answer to that question is performance. One essential characteristic of the crescent wing is thus its performance characteristic.

Therefore, in this paper, the matter will be introduced from a performance angle and an attempt will be made to show, in general terms, why there should be a performance gain from the crescent layout. Having established the case, the aerodynamic and aeroelastic characteristics will be considered in some detail so that, with these properties explained, the way will be clear to consider a performance comparison in greater detail and thus gain a fuller appreciation of the situation.

2. Performance Considerations

There is no layout or design formula that would be best for all specifications. It is clear that each specification must be considered on its merits, and what is right in one case will not necessarily be right in another.

In designing the Victor, we were concerned with a specification that called for long range with an appreciable load, a high cruising Mach number (which, of course, implied high critical Mach number) and a high cruising altitude. It appeared from this that the required characteristics were:

(*a*) A moderate or fairly large aspect ratio in order to get long range and high cruising altitude.

(*b*) A high sweepback to permit a reasonable thickness/chord ratio to be employed on the wing and yet to enable the specified high critical Mach number to be obtained.

To combine these desiderata is, unfortunately, inimical to good stalling behaviour since such a wing is liable to tip stall. "Tip stall" means that when a wing is brought to a high incidence, the stall begins at or near the tips. This is bad on a swept wing since loss of lift on the rearwardly disposed tips leads to a nose-up pitching moment or a self-stalling tendency; there is, in addition, the usual wing dropping danger with a tip stall.

The relationship between tip stalling and sweep and aspect ratio is shown in Fig. 1. This graph is divided into two regions, one marked "stable" and the other marked "unstable." If the wing in question plots in the stable region then it will be expected to be stable at the stall; if, however, it plots in the unstable region, then stalling behaviour is likely to demonstrate instability. It will be noticed that a rather wide band separates these two regions and this is because the boundary is not precise; in fact, it is only a sort of average boundary and must be regarded as giving a guide to the behaviour to be expected, rather than as having exact numerical significance.

There are two main reasons why high sweep is bad for tip stall: these are, firstly, its effect on load grading and, secondly, its effect on outflow. The effect on load grading can be seen from Fig. 2 which shows the distribution of local lift coefficient plotted along the span of an aeroplane for two cases, one without sweep and one with sweep. In the case without sweep, the local

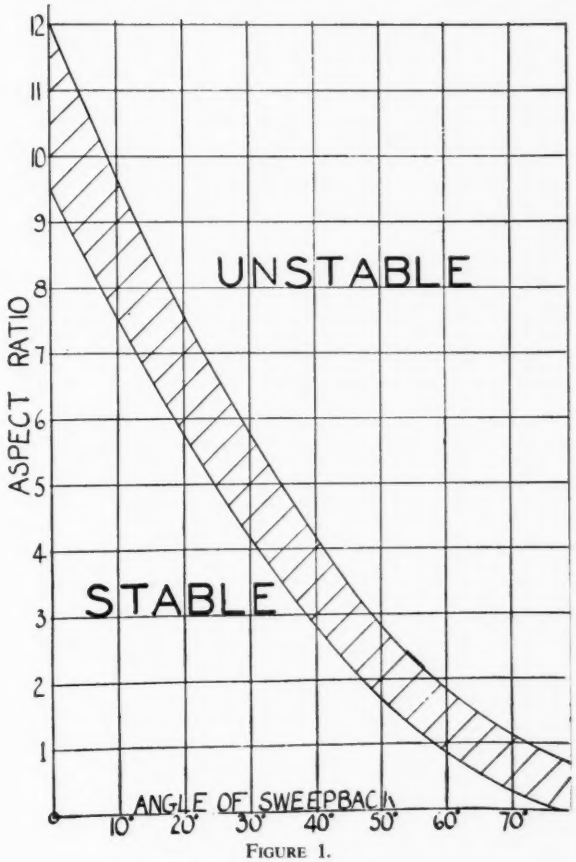


FIGURE 1.

Based on a Section Lecture given to the Society on 27th April 1954.

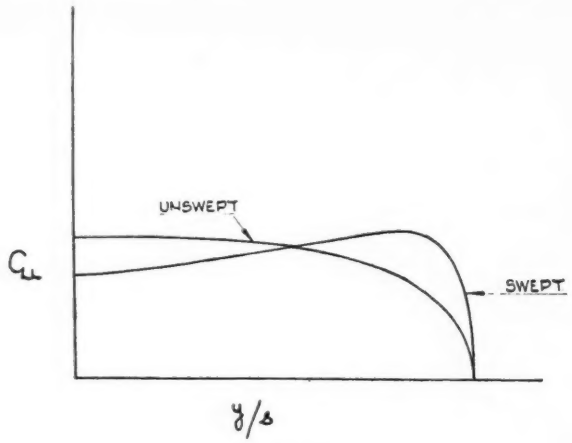


FIGURE 2.

lift coefficient is highest near the centre and falls off towards the tip, whereas for the swept case the reverse is true, the local lift coefficient being quite low near the centre and rising to a maximum just before the tip is reached. It is clear from this that, other things being equal, as the stall is approached, the swept wing will tend to stall first at the tip whereas the unswept wing will tend to stall first near the centre.

Consider now the question of outflow. By outflow is meant the drift of the boundary layer along the wing from the root towards the tip. This phenomenon becomes quite marked as a swept wing is brought up to the stall and the reason why it occurs may be seen from Figs. 3 and 4. Fig. 3 illustrates the behaviour of a streamline flowing obliquely into a pressure gradient. The left hand side of the figure shows what happens when the streamline enters an adverse gradient, while on the right hand side the streamline is shown entering a favourable gradient. Suppose that the streamline enters the pressure field obliquely such that θ is the angle between the streamline and a line at right-angles to the isobars or lines of equal pressure. This initial velocity V can be resolved into two components, $V\cos\theta$ at right-angles to the pressure gradient and $V\sin\theta$ parallel to the pressure gradient. The component parallel to the isobars, the $V\sin\theta$ component, will not be affected by the pressure and so when the streamline emerges from the pressure field, this component will be unchanged. The other component, *i.e.* the $V\cos\theta$ component, will be reduced by the act of traversing the adverse pressure gradient and it will come out with reduced magnitude. Thus, the relative magnitudes of these two components are altered by the pressure field and this, as is obvious from the figure, has the effect of swinging the streamline in a direction so that it tends to flow parallel to the isobars. In the other case, where the streamline is traversing a favourable pressure gradient, the tendency is for the cosine component to be increased with the result that the streamline emerges more nearly at right-angles to the isobars.

The pressure field on a typical swept wing near the stall is shown by Fig. 4. From this it will be seen that, over the greater part of the wing, the sweep of the isobars is such as to cause the boundary layer to tend to drift from root to tip over the rear part of the wing. Just at the tip it will tend to flow inwards for a very short distance so that what would be expected is that along a line somewhat as indicated by AB, there should

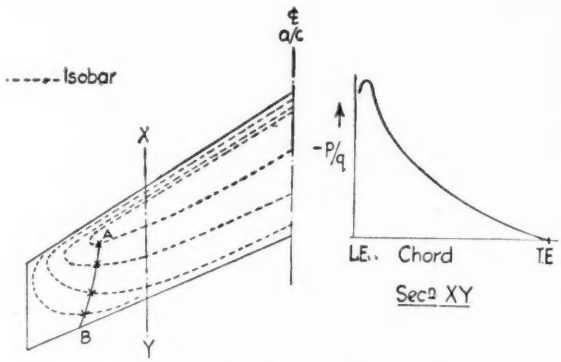


FIGURE 4 (*above*). Pressure distribution on swept-back wing.

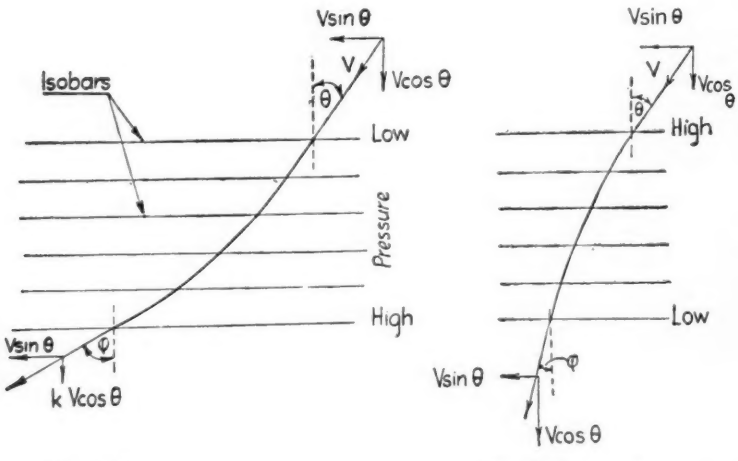


FIGURE 3 (*left*). Deflection of streamline by isobars.

$$\tan\phi = \frac{1}{k}\tan\theta$$

be a large accumulation of boundary layer drifting primarily from the root, with perhaps a little coming in from the tip as well.

This transference of boundary layer by means of outflow may be regarded in its effect on stalling as equivalent to positive and negative suction, *i.e.* equivalent to suction of the boundary layer through a porous surface. At the root where the boundary layer is removed, there is the effect of positive suction or removal of the boundary layer and this will delay the stall at the root. At the tip, on the other hand, the boundary layer is increased in volume and thus there is a sort of negative suction which will have the effect of reducing the maximum obtainable lift coefficient. From this it can be seen that outflow also acts in a way so as to promote a tip stall and to delay the stall at the root.

The way in which small aspect ratio helps tip stall is apparently as follows. In the first place, it modifies the load grading and smooths out the variation of local lift coefficient, *i.e.* there is less difference between the local lift coefficient at root and the maximum near the tip. In the second place, there is a peculiar and rather complicated three-dimensional effect due to the tip vortex which in some way seems to sweep up the boundary layer and in this manner offsets some of the effects of outward drift; this effect is undoubtedly of great importance and is probably the most important of the effects of aspect ratio. Finally, there is the effect on outflow itself which can be seen from Fig. 5. In the case of the high aspect ratio wing shown on the right, the boundary layer drifting out to the tip has a long distance to go and so will become thick; when it

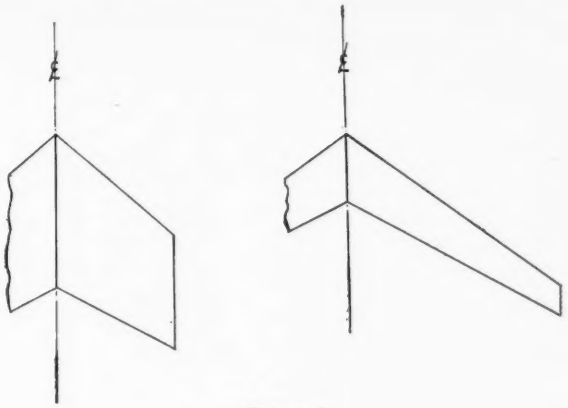


FIGURE 5.

gets to the tip, the chord there is small and the disruptive effect correspondingly large. On the other hand, with small aspect ratio the boundary layer does not have far to drift, thus remaining thin, while the tip chord is large, thus minimising the disturbance.

The crescent wing is a working compromise between the requirements for performance and the requirements for good tip stalling. Otherwise, the choice is between having high sweep and low aspect ratio, or moderate aspect ratio with moderate or small sweep and correspondingly thin wings. In the crescent wing, the aspect ratio is as large as necessary for performance and high

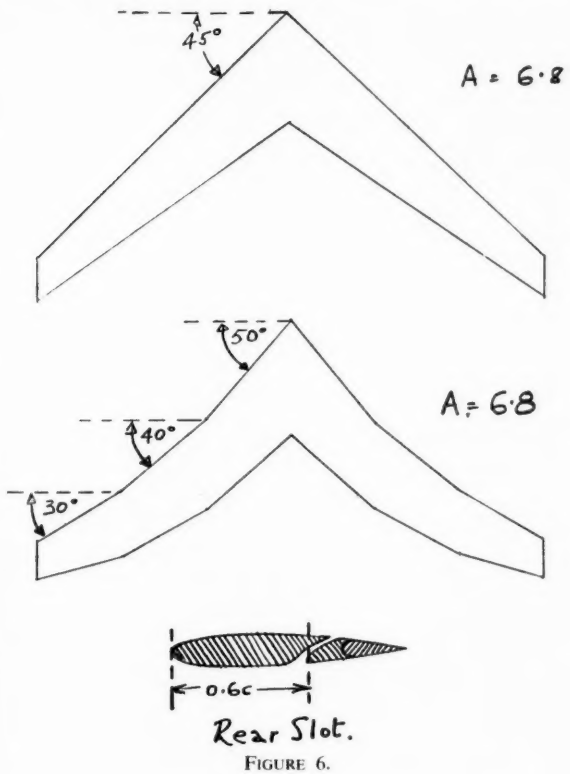


FIGURE 6.

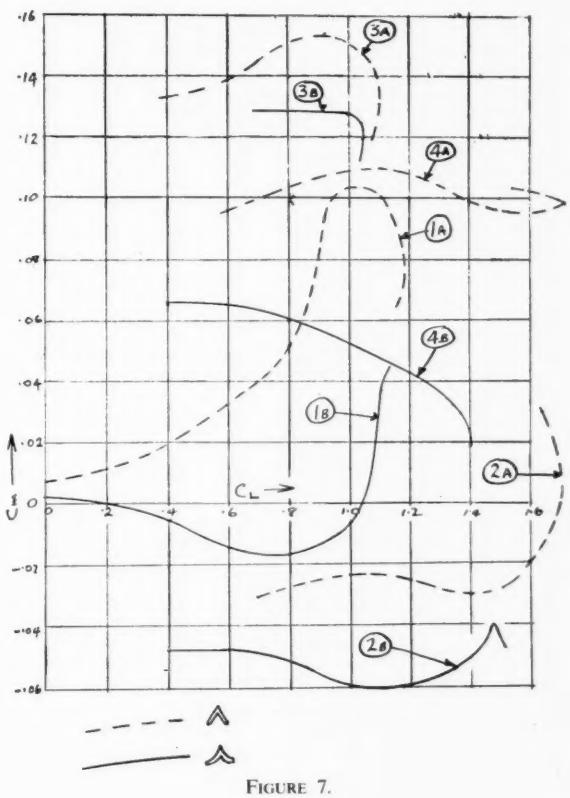
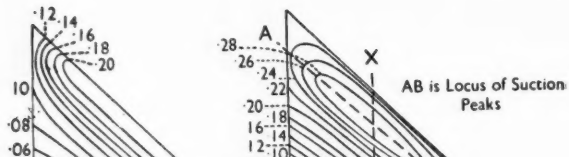


FIGURE 7.



Numbers are Values of Total Super-velocity

FIGURE 8.

sweep is obtained over the centre wing, permitting it to have a good thickness/chord ratio which is important structurally and for stowage reasons. By reducing the tip sweep, the tip stall problem is eased and the design penalty, a thin outer wing, is not too severe. The reduced tip sweep eases the outflow and the problem of the local lift coefficient. It was for reasons such as these that we started work on a wing whose sweep varied with span.

Having thus reviewed the crescent wing in general terms, its properties may be considered now in more detail.

3. Stalling

3.1. LOW SPEED

Typical early wind tunnel evidence in favour of the crescent wing is shown in Figs. 6 and 7. Fig. 6 shows two wings that were tested in the tunnel, an ordinary straight wing of 45° L.E. sweepback and a crescent wing with sweeps, on the leading edge again, of 50° at the root, 40° at the middle section and 30° at the tip. Both wings were of aspect ratio 6·8, which is rather high. The resulting pitching moment curves plotted against lift coefficient are shown on Fig. 7. The model configurations corresponding to the various curves are as follows:

Curve 1*A* 50 per cent. leading edge slot, no rear slot, flaps up, $\eta=0$

1*B* 53 per cent. leading edge slot, no rear slot, flaps up, $\eta=0$

2*A* 50 per cent. leading edge slot, no rear slot, flaps 57°, $\eta=0$

2*B* 53 per cent. leading edge slot, no rear slot, flaps 60°, $\eta=0$

3*A* 50 per cent. leading edge slot, 55 per cent. rear slot, flaps up, $\eta=-15°$

3*B* 53 per cent. leading edge slot, 10 per cent. rear slot, flaps up, $\eta=-15°$

4*A* 50 per cent. leading edge slot, 55 per cent. rear slot, flaps 57°, $\eta=-15°$

4*B* 53 per cent. leading edge slot, no rear slot, flaps 60°, $\eta=-15°$

NOTE: The *A* curves refer to the straight wing, the *B* curves refer to the crescent wing. η is elevator (or elevon) angle.

From this, the superiority of the crescent layout over the straight swept wing is evident in that the stability near the stall is always better in the crescent case than for the straight swept case. In addition, it is important to note that an extremely large rear slot was necessary to make the straight swept wing behave properly at all. The rear slot in question can be seen by reference to Fig. 6. Another point to notice is that as well as having better tip stalling properties, the crescent wing actually has a higher root sweep than the straight wing.

Despite the reduced sweep at the tips, the highly swept root does not want to stall, so there remains, even for the crescent wing, a tip stall tendency; this can be brought within reasonable bounds by the use of such normal aids as washout, careful choice of wing section, particularly camber, and also there is the fact that the wing-fuselage junction may in some cases be arranged so that it tends to promote a stall at the root. To sum up, as has already been said, the reduced sweep at the tip eases the local lift coefficient, reduces the outflow and so improves the stall of the tip section and, in addition, there is less cleaning-up of the root by the tips.

With regard to flaps and maximum lift coefficient, the high root sweep and the loss of the cleaning-up action from the tip does mean reduced maximum lift coefficient. Usually, this is not a serious disadvantage since the high altitude aircraft under consideration must have large wings in any case and big engines, so that the take-off and landing problems are not usually too difficult.

The reduced thickness/chord ratio at the tips would be embarrassing if carried to extremes to meet a very high critical Mach number since thin sections will have a low maximum lift coefficient. Thus, it is seen that this crescent layout can only be used within certain reasonable limits of design critical Mach number.

3.2. HIGH-SPEED (HIGH MACH NUMBER) STALL

Both the loss of sweep at the tips and also the sharp leading edge radius of these tip sections work together to produce favourable stalling behaviour at high Mach numbers and thus, for the crescent layout, one would expect the stall at high Mach number to be very good. The point to be remembered is that, for unswept wings, at any rate, a sharp leading edge radius is good at high Mach number at the stall, although it is poor at low Mach numbers.

4. Critical Mach Number

To get the desired (or design) critical Mach number it is clear that sweep and thickness/chord ratio must be matched along the span of the wing, for it is clearly desirable that all points on the wing shall have, as near as possible, the same critical Mach number; otherwise it would mean that some parts of the wing were unnecessarily thin or too highly swept, representing inefficient design.

This requires an accurate estimation of the pressure or isobar distribution over the wing, because from these isobar distributions the critical Mach number is estimated. In our case, this was done by analysing low

speed and high speed wind tunnel tests and calculated figures into the various component pressures due to fairing shape, twist, camber, lift, and so on, and then building up the high Mach number pressure distribution or isobar pattern, using high speed tunnel test results to show the effect of Mach number on pressure distributions. Having got this, the critical Mach number could be estimated. It should be pointed out here that since the isobar pattern depends on Mach number, when estimating the critical Mach number, it is necessary first to make a guess at what the critical is going to be, then estimate the isobar pattern and then from that estimate the critical Mach number; if this does not come out sufficiently close to the original guess, second or further approximations may be necessary.

Figure 8 illustrates two typical cases of a swept wing showing the low Mach number isobar distribution and the corresponding distribution at a Mach number of 0·85. Notice not only the change of supervelocity with Mach number but also the modification to the shape of the isobars.

5. Stability and Control

By stability and control is meant especially the stability and control for those flight cases where the flow is unseparated, *i.e.* not near the stall.

Aerodynamically, there is nothing very special about the crescent wing in this respect, in fact it acts much like a straight swept wing having about the same average sweep.

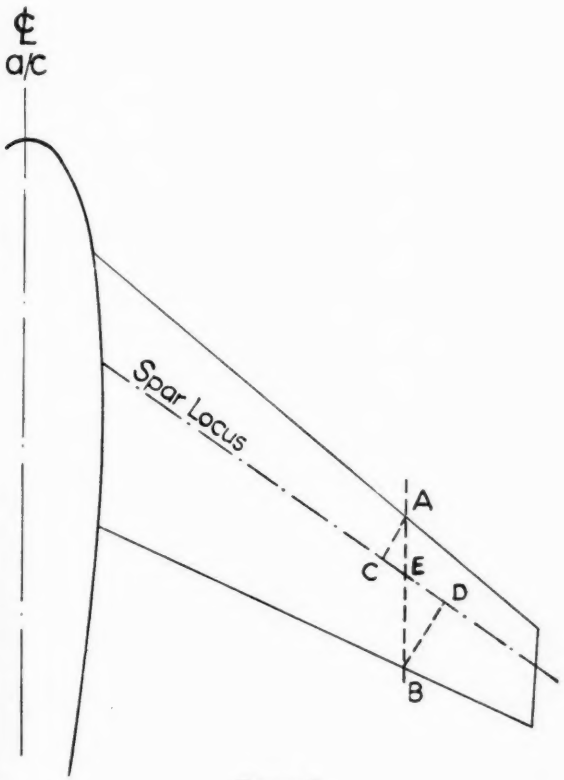


FIGURE 9.

With regard to ailerons at high Mach number, however, it is important that the tip sweep is not reduced too much as otherwise there may be a loss of control or even a reversal of aileron control at high Mach number. On the other hand, against this, a loss of tip sweep is obviously good for aileron power at low Mach number and especially, as discussed earlier, near the stall.

6. Aeroelastics

6.1. NON-OSCILLATORY CASES

Sweepback has a profound effect on the dynamic stability of an aircraft; that is to say, the manoeuvre margin is largely influenced by sweep when, as is always the case in practice, the wing is flexible. The basic reason for this can be seen from Fig. 9, which shows a typical swept-back wing. Imagine that this wing is being bent upwards by an up-load and it will be clear that the point *C* is lower than the point *D* since *D* is nearer the tip. Now, the point *A* which lies at right-angles to the spar from *C* will move approximately by the same amount that *C* moves, whereas the point *B* lying downwind of *A* moves by the same amount that *D* moves (since *BD* is at right-angles to the spar) and thus *B* will move upwards more than *A* does. The situation is therefore that the line *AB* is tilted downwards as the result of the upward bending of the wing and so one may say that, due to bending, a swept wing undergoes an increase of washout. This is potentially an embarrassing situation for, if the pilot began, say, a pull-out manoeuvre, then the increased up-load on the wings would bend them up which would produce washout, and the washout would tend to augment the pull-out already initiated by the pilot; in extreme cases this could be very dangerous and, in fact, it is an example of what is usually meant by saying that the manoeuvre margin is too small.

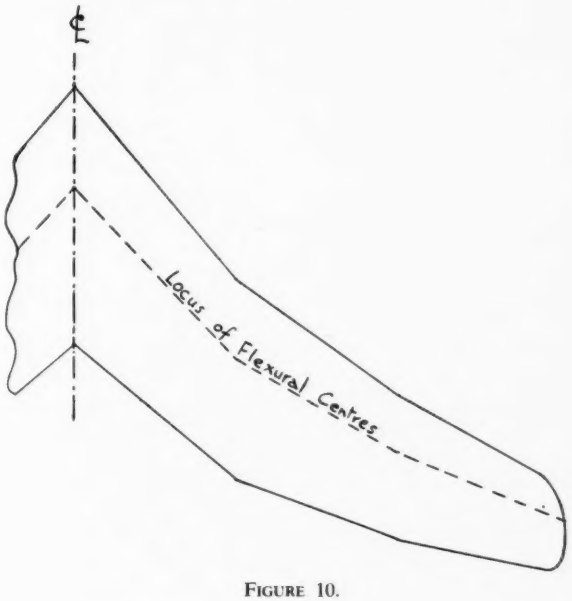


FIGURE 10.

One way in which this bending effect could be offset, or partly compensated, is by arranging for the wing to twist in a way so that twisting distortions cancel out bending distortions as far as aerodynamic incidence is concerned. To do this, it would be necessary to have the flexural axis well to the rear of the wing and the torsional stiffness would have to be fairly low; then, under the influence of upload, a wash-in would develop torsionally which would cancel out, or partly cancel out, the washout due to bending. This is not a very practical solution because, firstly, it is not usually possible to shift the flexural axis much and, secondly, flutter requirements and the requirements of aileron reversal would usually prohibit the use of a wing sufficiently flexible to enable this phenomenon to be very significant.

Here again, the crescent wing offers a useful compromise solution, for just as aerodynamically at the stall the crescent formula permits the use of a root with more sweep than would otherwise be possible, so it does the same trick aeroelastically by the reduced outer wing sweep and by producing a favourable twist over the centre wing. This latter effect is very important and its reason can be seen from Fig. 10 which shows clearly that an upload on the outer wing acts well forward of the projection of the flexural axis of the centre wing; this means that an up-load on the outer wing will cause the centre wing to twist in a way so as to produce wash-in on the wing. This, it will be remembered, is what was required to compensate for the bending effect, or rather to compensate for the washout effect due to bending. Thus the crescent wing is favourable aeroelastically on these two counts: firstly, the outer wing has reduced sweep and correspondingly reduced washout effect due to bending, and, secondly, there is this most important favourable torsion induced over the inner parts of the wing.

6.2. AILERON REVERSAL

The crescent wing is not very different in this respect from other swept wings since, even in the swept case, aileron reversal is, to quite a large extent, an affair of torsional stiffness. Bending stiffness does play a part and, since this is so, the crescent wing is favourable because of the reduced sweep that it has over the outer part of the wing (which is the most important part where rolling is concerned) and since the favourable characteristics already described in connection with manoeuvre margin are beneficial in this case too.

6.3. FLUTTER

It is not possible to generalise on the effect of the crescent layout on flutter. There is not any simple treatment and the results that have been obtained so far do not indicate any special features that could be directly attributed to the crescent plan form. The flutter work was rather complicated and because of this, for the "Victor," flutter models were used and tested in the tunnel. The main reason for these flutter models was uncertainty regarding the aerodynamic derivatives applicable to the crescent wing; it was felt that these tests would also show up any peculiarities due to the crescent structure should they exist. It should be emphasised that flutter clearance was not confined to tunnel work but, ultimately, was based, in the normal manner, on calculations built up on resonance tests done on the complete aeroplane.

7. Performance

Having thus considered in some detail the special characteristics of the crescent wing, it is now convenient to consider, in more detail, the performance aspects by reviewing the possible solutions that might be reached in attempting to satisfy the specification referred to at the beginning of this paper, *i.e.* for a long-range aircraft carrying a good load, having a high critical Mach number and a high cruising altitude.

An aircraft which meets the specification under consideration must have the following characteristics:

1. High critical Mach number, because the cruising cannot be carried out in a condition with any appreciable drag rise since a good lift/drag ratio must be obtained.
2. Good cruising lift/drag ratio.
3. Good tip stall.
4. Good manoeuvrability.
5. Adequate take-off and landing.
6. Freedom from flutter.

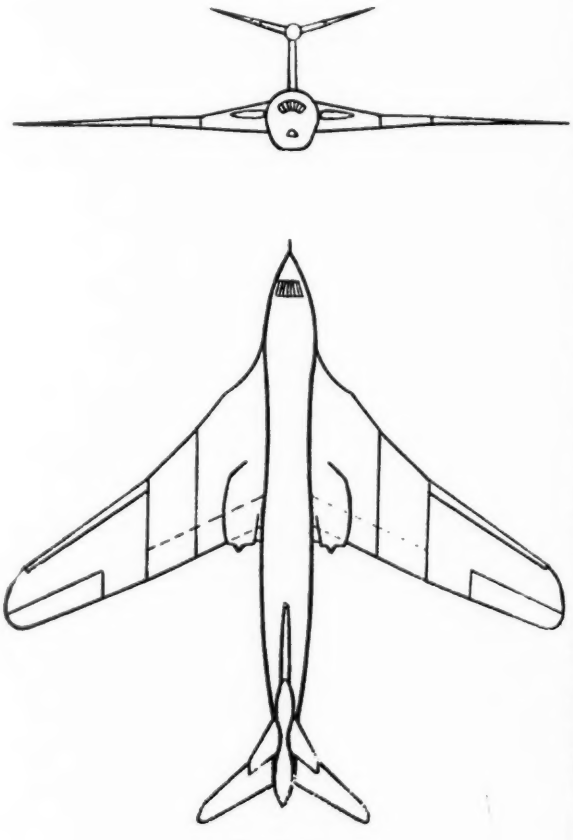


FIGURE 11.

TABLE I

Problem	Solutions:		
	Podded layout	Delta layout	Crescent layout
Tip stall	Engine nacelles	Small aspect ratio	Less sweep at the tip
Flaps		Large wing area offsets low maximum lift coefficient	
Manoeuvre margin	Poor; twist from engines is wrong	Stiff wing	Plan form helps
Flutter	Engine mass-balance	Stiff wing	Normal

Combined with all these requirements, there must always be a good structure weight, adequate accommodation for the crew and load, and the aircraft must be able to carry out whatever operational role it may have to perform.

There are, currently, three different solutions to this problem:

(*i*) The high aspect-ratio layout favoured by the Americans and especially by the Boeing Company. With this layout the engines are usually installed in external pods.

(*ii*) The delta layout.

(*iii*) The crescent plan form, *see* Fig. 11.

The relative merits of the three layouts are now considered.

Assuming that the critical Mach number is equal in all the cases considered, the value of the lift/drag ratio that can be obtained follows from the way in which the remaining problems are solved. In Table I the four primary problems, namely, tip stall, take-off and landing (referred to under the general title of flaps), manoeuvre margin and flutter are tabulated and the table shows the different ways in which these problems are tackled by the three different layouts. The following comments on this table should be made.

Firstly, with regard to tip stall, the engine nacelles help the podded layout because, apparently, they direct the air in a direction more or less parallel to the chord, *i.e.* near the tip they reduce the local angle of incidence at high angles of attack and the engine supports act partly as "fences." (It must be remembered that in a typical podded layout, the outer nacelles are quite near the tip). The way in which the delta layout gets over its stall problems is by using its lower aspect ratio. As for the crescent layout, the stalling behaviour of this type of wing has already been discussed.

On the question of manoeuvre margin, it will be seen that the weight relief from the engines is wrong on the podded layout; since the engines are far forward of the spars they will tend to promote washout under "*g*," whereas what is required under these conditions is wash-in.

Regarding flutter, again a special note is necessary in connection with the podded layout since it is in this layout that great use is made of the mass balancing effect of the engines which, by being disposed correctly, permit a reduction of torsional stiffness appreciably below that which would otherwise be necessary.

Having thus summarised, very briefly, the main characteristics of these three layouts, an attempt will be made to try to see what may be expected in the way of performance from the three types of aircraft. It must be emphasised here that the figures quoted are generalised figures based on over-all rather than detailed considerations and it is obviously possible that in any particular case some special circumstance might arise which would invalidate the numbers quoted. It is felt that despite this, the trend illustrated by the figures is reasonably correct and therefore, although it is a somewhat hazardous business to deal with performance figures so briefly, it is hoped that there is some value to the table which follows.

Table II, it will be seen, compares the parasite drags of the three layouts and, as a standard of reference, the podded layout has been taken. All drags are quoted as fractions of the total parasite drag of the podded layout, written as D_p. As a starting point, the spans of all three aircraft have been assumed to be equal because this means that when flying at the same weight, height and speed (or Mach number), the induced drags of these three types will be substantially the same; therefore, a comparison of the parasite drags should illustrate, or show up, the differences to be expected between the three layouts. Typical figures are given for the appropriate wing areas, again expressed in terms of that for the podded layout. It will be seen that nacelle drag is quoted as a special item, as is fuselage drag. Of these two, obviously, the nacelle drag is highest for the podded layout, while the fuselage drag is smallest for the delta layout since the large wing enables fuel and perhaps other load to be stored in the wing. The item headed "Remaining Drag" includes tail unit drag and here again the delta drag is the smallest because it has only a vertical surface and no horizontal tailplane.

When all these drags are added up, it will be seen that the total parasite drag, or drag at 100 f.p.s. at zero lift, of the podded and crescent wing layouts are almost equal and that of the delta layout is some 20 per cent. higher than this. For optimum range, flight will be taking place under conditions close to those giving maximum lift/drag ratio; this means that induced drags and parasite drags will be approximately equal. Thus, comparing the delta with the other two types, since they all have equal induced drags and since the parasite drag of the delta is 20 per cent. higher than that of the other

TABLE II

	Podded	*Tailless delta*	*Crescent*
Span	b	b	b
Wing area	S	$2{\cdot}5S$	$1{\cdot}5S$
Wing drag, D_{100}	$0{\cdot}33D_p$	$0{\cdot}85D_p$	$0{\cdot}49D_p$
Nacelle drag, D_{100}	$0{\cdot}15D_p$	$0{\cdot}02D_p$	$0{\cdot}02D_p$
Fuselage drag, D_{100}	$0{\cdot}27D_p$	$0{\cdot}15D_p$	$0{\cdot}25D_p$
Remaining drag, D_{100}	$0{\cdot}25D_p$	$0{\cdot}18D_p$	$0{\cdot}25D_p$
Total drag, D_{100}	D_p	$1{\cdot}20D_p$	$1{\cdot}01D_p$

two, it may be concluded that the total drag of the delta is some 10 per cent. higher than that for the other two layouts. Alternatively, it may be argued that the delta wing is unnecessarily large and that the correct thing to do is to cut down the span. If this is done and, for example, the span of the delta is reduced to 90 per cent. of that of the other two aircraft, then wing drag for the delta at zero lift will be down by 20 per cent., *i.e.* by $0{\cdot}17\,D_p$, so that for this smaller delta, the total parasite drag or D_{100} would be approximately equal to that of the other two layouts; however, because the span is now 10 per cent. down, the induced drag will be up by about 20 per cent., once again giving the delta aircraft about 10 per cent. more total drag than the other two types.

From this it would be expected that the drag of the delta, whatever its precise proportions, would be higher than that of the podded or crescent layouts.

Having considered the drag question briefly, it is necessary now to consider the weight side of the matter. It is not possible to make anything like a proper weight estimate, but it is possible to consider weight trends. These trends are as follows:

Podded wing—This wing has small thickness and torque box area but has very good weight relief due to the engine disposition, small wing area and an unbroken structure.

Delta wing—This wing has large thickness and torque box area but small engine weight relief and much the largest gross area and a high rib weight; from this, it would be expected that the delta wing weight would be the highest.

Crescent wing—This has moderate thickness, moderate torque box area and moderate wing surface area combined with small weight relief.

Considering fuselage weights, the weight of that for the podded aircraft is probably largest because the undercarriage has to be stowed in this fuselage which must upset fuselage design. The delta fuselage is probably the lightest because it is a small one.

On the question of tail units, here again, the weight of the delta tail should be the lightest.

The general conclusion on weight seems to be that it is unlikely that there is a great deal in it either way, since the three layouts are fairly equal throughout. The crescent and the podded wings have a fairly similar weight distribution; the delta weight distribution is different, and what it loses on the wing it gains on the fuselage and the tail. (This is, of course, provided that there is operationally no objection to the fuselage being smaller than on the other layouts).

A 10 per cent. improvement in lift/drag ratio may not seem very much at first but at long ranges where the useful load may be quite small, only 5 per cent. or 10 per cent. of the all-up weight, and the fuel about half the all-up weight, then 10 per cent. off the fuel weight adds 50 per cent. or 100 per cent. more to the load that can be carried. Thus for a long range aeroplane, an extra 10 per cent. on L/D ratio is undoubtedly worth while.

8. General Summary

Having thus briefly reviewed the whole matter, it is perhaps possible to attempt a short summing up of the main points under consideration.

Critical Mach Numbers—These have been assumed equal for all cases.

Range/Load Performance—The crescent and the podded layouts seem to be about equal and both a bit better than the delta.

Operational Height—The crescent and the delta are both better than the podded layout which suffers from its high wing loading, which will reduce cruising altitude and will badly restrict manoeuvrability at altitude.

Take-off and Landing—The crescent and the delta layouts are both satisfactory here and much better than the podded layout, which suffers, as explained above, from high wing loading.

Manoeuvrability at Height and at High Equivalent Air Speed—Here, the crescent and the delta are both satisfactory and both better than the podded layout which, as explained earlier, suffers from its high wing loading and the rather bad aeroelastic properties as affecting manoeuvre margin.

Super-critical speed—In flight at speeds above the critical, the crescent and the delta are both cleaner than the podded layouts and one would therefore imagine that they would perform better once M_{crit} is passed, or, at any rate, one would expect that the super-critical drag rise would be less steep.

9. Conclusion

The crescent layout is thus seen to provide an efficient and manoeuvrable aeroplane capable of satisfying an exacting specification. It is not the only way of meeting the requirements, but there are good grounds for believing it to be the best alternative for the specification in question.

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The Investigation of Aircraft Accidents and Incidents

AN INTRODUCTORY STUDY

by

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SUMMARY: Attention is confined to civil aviation and the present scope of investigating procedures is outlined on a world-wide basis. Deficiencies in these procedures are noted and some suggestions are made for possible future developments of technique. In particular it is suggested that there can be little progress in air safety without the assimilation of "human engineering data" by investigators and the Industry alike. Opinions expressed are entirely personal to the author and are not associated in any way with the official views of The British Aviation Insurance Co. Ltd.

1. Introduction

Although the scope of this paper is confined to current civil air transport, many of the general remarks may be found applicable to military accident investigations and to the investigation of prototype aircraft accidents. These two latter categories have their own problems, too specialised to be dealt with here.

Why investigate accidents? Most people feel they have an intuitive answer to this question and yet in practice there seem to be as many answers as there are countries in the world. Some States initiate investigations merely to ensure that their own legal liabilities are not prejudiced; not a few pilots regard investigations as the inevitable prologue to disciplinary action; and the aviation enthusiast believes there is a firm connection between investigation and air safety. The connection is not a firm one yet, indeed except possibly in the realm of airworthiness, there is often only a tenuous link between the *occurrence* of an accident or incident and any subsequent improvement in air safety.

In one sense the whole of aviation progress is the result of investigations of one kind or another. The early pioneers often had only their personal accident records to assist them in their next designs and the application of their analyses was a fine blend of the human and the material factors involved. Today, vast effort is expended on research into performance possibilities and structural possibilities, but until recently, disproportionately little attention has been directed to human possibilities.

No excuse need be offered, therefore, for an attempt to define the objectives of an ideal accident or incident investigation:

"To provide scientifically valid data arising from accidents or incidents which shall assist in preventing future similar occurrences and generally contribute to safer aviation."

It is unfortunately necessary to use the clumsy phrase "scientifically valid data" to distinguish between that and mere "legally valid data" which is so often the major official result of investigations in terms of compliance with regulations, contraventions and so on. Moreover, it is necessary to define "investigation" in terms of the use to which data will be put—an investigator with little idea of the purpose of his work cannot produce useful material and an investigation directed at ascertaining only the circumstances of an accident, will rarely contribute to the prevention of other accidents whether related or not. Finally it is necessary to specify that the data shall not only assist in preventing future *similar* occurrences but also "generally contribute to safer aviation." This is done because an investigation is one of the rare occasions when a *detailed* examination of, for example, operational or maintenance practice is possible, and very often there are revealed potential hazards which contributed nothing to the particular incident, but in the interests of future safety are best eliminated.

It is worth while noting that where State investigations are concerned, the purpose of an investigation may simply be to satisfy the legal requirements consequent upon an accident, whereas the only justification of an ideal investigation is a resulting improvement in air safety. Sometimes the two objectives coincide but there is no necessity and indeed it is not always desirable. If an attempt were made to make these two objectives coincide always in the interests of air safety, the result would be a mass of highly detailed legislation, heavily prohibitive in application and practically impossible to enforce. Some kind of compromise has to be achieved and all it is proposed to say at this stage is that in all countries

(*a*) It should be possible to conduct investigations into those accidents or incidents which the local law does not require to be investigated.

(*b*) All accidents or incidents which require investigation in the interests of air safety need not be required to be investigated according to local law.

Based on a lecture given to the Graduates' and Students' Section on 22nd April 1953.

Meanwhile it is clear that there are five main stages involved in linking the *occurrence* of an accident or incident with a resulting *improvement* in air safety:

1. Prompt notification of occurrence to the appropriate authority.
2. " Ideal " investigation by a competent authority.
3. Data analysis and formulation of recommendations by a competent authority in consultation with those who will be involved in the implementation of recommendations.
4. Publication of data, analysis and recommendations to persons concerned directly or indirectly with the circumstances of the accident and to those concerned with the implementation of recommendations.
5. Implementation of recommendations by persons concerned. (Including the publication of useful results to as wide an aviation community as possible).

There is scope for a great deal of research on each of these five stages. This paper will attempt to outline some of the problems involved in Stage 2—" The Investigation," but since Stage 2 is dependent on Stage 1—" Notification " and has to be defined in terms of Stage 5—" Implementation," some reference must inevitably be made to all the associated stages involved in translating investigation into air safety. It will be apparent that the word " investigation " is being used in the sense recommended by the International Civil Aviation Organisation (I.C.A.O.), *i.e.* restricted to the actual gathering of pertinent data. The term " inquiry " will be reserved for the more formal process of analysis, whether public or not.

It is appropriate here to remark that the Royal Aeronautical Society was evidently active in encouraging one of the first systematic studies of aircraft accidents in this country. An Accidents Investigation Committee was formed under the chairmanship of Colonel Holden, F.R.Ae.S., and they investigated their first accident on 13th May 1912. At the discussion following Colonel Holden's report in the form of a lecture on 18th March 1914[2], it was asked by Dr. A. P. Thurston " When one considered the valuable information obtained from investigations into the causes of fatal accidents, why an investigation into every accident in which the machine was damaged was not made?" We have advanced in our investigations since those days, but not a great deal. As recently as 1949 at the conference on Air Safety[1], doubts were expressed as to whether the best value was being derived from accident investigation and Dr. Roxbee Cox called attention to the value of *incident* reporting.

Although attention has been drawn from time to time to the limitations of human beings called upon to operate air transport, practical exploration and implementation of these factors has been slow. Some of the warnings have been recorded in this JOURNAL; for example:

1914 Colonel Holden—" Instruments . . . should be clearly legible in their indication, accurate, and so placed that the pilot has to distract his attention as little as possible from his work to read them; above all, however, they must be reliable."[2]

1925 Major General Sir Sefton Brancker—on errors of judgment—" From the beginning of aviation the designer has always been prone to assume that his aircraft would be flown by an absolutely first class pilot."[3]

1932 Capt. A. G. Lamplugh—drew attention to the significance of pilot error and asked among other things for " design with a view to improved visibility."[4]

1949 Dr. K. G. Bergin—commented on some of the human factors involved in accidents.[1]

1951 Mr. W. Tye—was among the first to draw attention to the value of " human engineering " data and commented on approach and navigational aids—" Systems which require an acquired skill to interpret seem to be potentially dangerous."[5]

1951 Group Captain J. A. Newton—devoted a whole paper to " The Human Factor in Aircraft Accidents."[6]

2. Outline of Ideal Investigation

To obtain some idea of the work involved in conducting an ideal investigation it will be necessary to try and abandon any preconceived notions of the work of an average investigator. In what follows, the word " accident " will be used to include the notion of an " incident " unless a contrary intention is specifically expressed. An "incident" may be any unexpected event arising out of aircraft operations which might threaten harm to any person*, while an " accident " is an incident which has resulted in material damage or human injuries.

It is better to reserve the term " inquiry " for the formal presentation and analysis of evidence required by State legislation, or required by an operator's code of procedure. For convenience sake, " investigation " will be understood to relate to the actual gathering of data before formal analysis. In fact there is no sharp demarcation between practical investigation and practical analysis.

The objectives of an ideal investigation as stated in the Introduction were:

" To provide scientifically valid data arising from accidents which shall assist in preventing future similar occurrences *and* generally contribute to safer aviation."

To achieve this it is necessary that there should be prompt notification of the accident to an appropriate authority. Now the appropriate authority need not be the State—it can be the aircraft operator or the aircraft manufacturer. It is not easy to secure the universally prompt reporting of incidents (as distinguished from accidents) because of the many elements of personal, company, departmental or national pride which may exist. This problem (and some possible solutions) will be referred to again later; for the time being it is sufficient to assert that universally prompt reporting must exist before investigation can begin.

Next it is necessary that evidence by way of wreckage, witnesses and the like shall be preserved pending the arrival of competent investigators. This is usually no great problem where the accident and the investigator are both in the same country, but there can be difficulties when the investigator is many thousands of miles from

*Note this is similar to the definition of an accident in the United Kingdom Civil Aviation (Investigation of Accidents) Regulations 1951[7].

his evidence and the country where the accident has occurred has no interest in the preservation of evidence. Fortunately those countries which have implemented the provisions of I.C.A.O. Annexes 9[8] and 13[9] have agreed procedures for preserving evidence and facilitating the interchange of investigators. There are still large areas of the world where an investigator would be uncertain of:

(*a*) being allowed to examine evidence and conduct investigations
(*b*) finding evidence undisturbed.

It is clear that undisturbed preservation of, and access to, evidence are essential before an ideal investigation can begin.

The ideal investigator (often assisted by a team of specialists) will arrive at the scene of an accident with a minimum of delay and, after presenting his credentials to the local authorities who are preserving evidence for him, he will proceed to examine and record pertinent data systematically. The questions are—what is pertinent data and what sort of system should be employed?

Unfortunately, no two accidents are ever quite the same and hence only general guidance can be given on these important questions. For example, it is always important that a wreckage trail should be examined, mapped and photographed without delay and it is always important to examine witnesses while their memories are fresh and there have been few opportunities for reflection, imagination and perhaps talk with other vital witnesses, supervising staff and so on.

Moreover, the data which is pertinent to a nearly-missed collision in perfect weather is not the same data which is pertinent to a structural break-up in cumulonimbus cloud. Some idea of the variety of questions which the investigator must try and answer is given in the I.C.A.O. Manual of Aircraft Accident Investigation (Second Edition)[10]. In spite of this apparently interminable complexity, the evidence which should be collected in an ideal investigation must aim at including some or all of the following:

Data usually collected in the vicinity of the accident:

1. Description of salient features of the aircraft and all on board. (This will include all aircraft and crew documentation).
2. Purpose of flight.
3. Description of circumstances of accident (from a variety of sources).
4. Reconstruction of physical sequence of events leading up to and during accident. (This will include any mechanical failures encountered and the sequence of, for example, the final disintegration).
5. Reconstruction of human sequence of events leading to accident. (This is not often possible but where relevant would include for example, crewing arrangements, rest periods and vital actions up to and including the accident).
6. Ancillary data, *e.g.*
   (*i*) The operation of aircraft emergency devices.
   (*ii*) The operation of ground emergency procedures.
   (*iii*) Mode of initiation and spread of fire*.
   (*iv*) Cause, distribution and nature of injuries†.
   (*v*) Operation of ground emergency services such as fire and search and rescue.

Quasi-analytical data sometimes collected away from the accident vicinity but requiring to be borne in mind at all times by the investigator.

7. Analysis of chain of causation of physical and human events leading up to and including the accident.
8. Responsibilities involved in the events forming the chain of causation.
9. Relevance and suitability of various regulations relating to the circumstances of the accident, *e.g.*
   International Standards
   State Regulations
   Operators regulations
   (Company procedures)
   Airfield regulations, and so on.
10. The inter-relation of the responsibilities (involved in the chain of causation) and the regulations (relating to the circumstances of the accident).
11. Analysis of any other features which, although potential threats to air safety, have not been directly involved in the chain of causation of the particular investigation.
12. Design of recommendations "which shall assist in preventing future similar occurrences." (Based on items 7 to 10).
13. Design of recommendations "which shall generally contribute to safer aviation." (Based on item 11).

It is sometimes argued that it should be no part of an investigator's duties to ascertain the responsibilities involved in the manifold causes of an accident, or that he should not be concerned with the design of recommendations. This is an extraordinary misconception of the function of investigation. Possibly it arises from the primitive idea of an accident investigator as one who is concerned only with the examination of wreckage. The modern investigator (and this section is outlining the "ideal" investigation) is often the leader of a large team of which the wreckage analysers are only one unit.

It is not enough for the investigator to ascertain that the accident was caused by the aircraft striking a mountain. He must forever be asking, why? He must repeat this question until he can go no further and he reaches such fundamentals as, perhaps, an inadequate navigation course producing an errant navigator, or a fault in Air Traffic Control procedure resulting in a

*See, for example, "Suggested Check List for Investigating the Fire Aspects of Aircraft Accidents" and "Aircraft Fire Report Form" issued by the National Fire Protection Association of America.

†See, for example, "Handbook for Aircraft Accident Investigators Co-operating in Crash Injury Research" issued by Cornell University Medical College.

failure to action vital information. It is absurd to suppose that the investigator can go on asking why without at the same time encountering questions of conflicting responsibilities. It is equally impossible to investigate without any idea of the ultimate purpose of investigation and hence the investigator must bear in mind *from the outset* that his work is intended to assist in the design of helpful recommendations.

Clearly this imposes a tremendous burden, even on the ideal investigator, who must have ready access to an unknown variety of specialist advice. In practice, there are limitations to the ability of individual investigators, there are limits to the time which can be devoted to investigation and perhaps most important of all, there are limits to the money which can be spent.

The ideal investigator has the formidable task of linking the occurrence of an accident with some resulting gain in air safety and it is suggested that this can only be done effectively where the team-leading investigator plays a key role in each of the three major processes:

(*a*) Investigation—in direct contact with the primary data.
(*b*) Analysis and recommendations—in direct contact with the planning authorities.
(*c*) Implementation—in direct contact with the limitations of men and machines.

The allocation of these functions to separate State agencies can have disastrous results when, as can so easily happen, the planning authorities are not in *direct* contact either with the primary data, or the organisations engaged on actual implementation. The link between all three functions should be the original investigator and this applies regardless of the method chosen to operate each function. For example, a committee or a public court is often chosen for the analysis and recommendatory function. The ideal investigator should still be their guide. In fact the committee's work can rarely be any better in quality than the basic data produced by the investigator. Nor is it possible for the investigator to make all his results available in an adequate written form which can then be handed on from committee to committee for action. Unless the investigator's report includes written conclusions, no two people would summarise his results in quite the same way, and perspective would be lost in an all too familiar fashion. But if the report is to contain conclusions, the investigator is involved in analysis; if he is involved in analysis then he is already forming recommendations and to do this he must be aware of the possibilities of implementation.

All this may appear at first sight to be a counsel of idle perfection. In the later Sections of this paper it will be suggested not only that such methods are vital to the progress of air safety, but that there are practicable methods of conducting "ideal" investigations.

3. Who Investigates and Why

The preceding Section outlined the requirements for an "ideal" investigation. It is appropriate now to compare the ideal requirements with the existing practical organisations for investigation. This Section, therefore, will describe the main types of agency concerned with accident investigation and outline their motives. Subsequent sections will give some idea of *which* accidents are investigated, *how* the procedures work and finally indicate the main results of investigations. These divisions are for convenience only and the topics must inevitably overlap.

In those countries usually classified broadly as belonging to Western Civilisation there seem to be four main agencies for the investigation of aircraft accidents:

1. The State.
2. The aircraft operator.
3. The aircraft manufacturer (or designer).
4. The aircraft insurer.

Each of these agencies may attempt to conduct an entirely independent investigation but in practice, each one (except the insurer) may have to supply vital and original data for analysis. It is obvious, therefore, that there must be considerable co-operation between all the agencies.

3.1. THE STATE

Most states which own civil aircraft or have civil aircraft within their dominion assume the responsibility of regulating flying by these aircraft in the interests of what is loosely called public policy and public safety. When an important accident occurs (*i.e.* involving considerable aircraft or property damage, injuries or deaths) most states institute inquiries for any or all of the following reasons

(*a*) To comply with state regulations concerning accident or criminal investigation.
(*b*) To satisfy public opinion.
(*c*) For political reasons.

Those states which have implemented the I.C.A.O. Convention (Chicago 1944)[11] agree that the state in which an accident occurs shall conduct the investigation either with, or without, the active co-operation of the state of registry of the aircraft involved. The procedures of I.C.A.O. Annex 13[9] recognise that the state of occurrence may have little interest in the accident and may, therefore, delegate the whole or part of the investigation to the state of registry. Even in "I.C.A.O.-type" states it is clear that a busy air-traffic transit state need have no investigation staff, whereas a state controlling hundreds of aircraft will need an elaborate investigation organisation.

State machinery for investigation is different in every country of the world and it is not possible even to attempt a summary here. The actual investigators may range from a large staff of full-time specialists (*e.g.* the U.S.A. and the U.K.), to one or two civil servants who investigate accidents as an incidental to their principal occupation, which may or may not be connected with the administration of air transport.

It is important to realise that every accident or incident ought deeply to concern a conscientious state of registry. For example, if a material failure is a principal cause then the state of registry was either unable to predict its possibility or ensure that its occurrence would not have serious results (that such predictions may be beyond the current boundaries of human knowledge

is irrelevant for this argument). Or if a particular personnel error is revealed then the state of registry either failed to exercise such supervision as would preclude such errors, or was unable to ensure that this error would not have serious results. (The assumption of such all-embracing responsibilities by a conscientious State does not imply the detailed control and supervision of every aspect of aviation by civil servants. Rather does it imply that the broad policy makes provision for adequate pure and applied research, while the regulations themselves should allow scope for the development of ideas in the airline industry).

These are extreme arguments which, in practice, are usually recognised by *attempting* to make the State investigators independent of any other state department administering aviation. Since the investigators usually need statutory authority to do their work efficiently it is often difficult to make this independence perfect. The natural tendency is often, therefore, to regard the results of state investigations into state responsibilities with some reserve, unless the state normally has a high reputation for justice and integrity among its civil servants.

3.2. THE AIRCRAFT OPERATOR

The operating company whose aircraft is involved in an accident always has the most pressing reasons for conducting a detailed investigation. The operator is the one agency who must know almost immediately what can be done to eliminate the possibility of a recurrence. Is the aircraft safe? Are the crews competent? Is the weather forecasting adequate? This is the type of question which the operator must ask and answer immediately. It might be thought, therefore, that every operator owning more than two or three aircraft would

(*a*) Have access to a competent investigator.
(*b*) Be accorded priority in official investigations.

The facts are that only the leading airlines have specialised investigating staff, while the majority of the remainder do not have access to experienced investigators. Not all states which have implemented I.C.A.O. Annex 13[9] accord full co-operation to the operator's investigator, although they may well use one of the operator's technical specialists as an advisor.

The operator has the best chance of all of successfully investigating *incidents* and all those accidents which, for one reason or another, are not investigated by the state. (*See* Section 4).

The machinery whereby operators carry out investigations may be as varied as the different states. The following are the main types of investigation organisation within an operating company:

(*a*) An Air Safety Department or Safety Analysis Section concerned with the overall study, investigation and implementation of air safety. This is the most highly developed and satisfactory type of organisation, usually reporting and acting at management level.
(*b*) An Accident Investigation Department often assisting in aircraft defects investigation.
(*c*) *Ad-hoc* committees of specialists, either permanently sitting or formed specially to investigate particular accidents.
(*d*) Investigation by individuals (*e.g.* the Flight Superintendent) followed by committees to study disciplinary action.
(*e*) No special organisation; either with or without access to an external independent investigator.

3.3. THE AIRCRAFT MANUFACTURER (OR DESIGNER)

The designer or manufacturer of a production civil aircraft has the keenest interest in all accidents which are attributable to defects in performance, faults in design, lack of airworthiness or mechanical failures. The manufacturer tends not to be interested in those accidents attributable to personnel error, unless it is brought to the designers' attention that an alteration in design would either minimise particular personnel errors, or render the consequences of such errors harmless.

Hence in all but a very few cases, aircraft manufacturers do not possess accident investigation staff although they may possess a defect investigation department. Manufacturers are often invited to collaborate in State investigations by supplying specialist technicians (*e.g.* test pilot, or on airframe, engines, hydraulics and so on) to act as advisors. Usually they are content to remain in this role and indeed this would probably be an ideal role if it were possible to be sure that the inter-action of design features on personnel errors was a topic always fully explored by other investigators. Unfortunately, this is not always so and it is certain that manufacturers could play a more useful part in investigations if they had staff, not only intimately familiar with their own products, but also skilled in the overall analysis of accident data.

The difference between possessing expert technicians and possessing skilled accident investigators is exemplified whenever someone mishandles an aircraft. The manufacturer is often astonished that anyone could mishandle his machine—" our test pilot has no difficulty " it is said, or "our engineers have never made that mistake." The designer has to be reminded that an average pilot in trying circumstances may react very differently from a specialised test pilot.

The manufacturers' present position may be summarised by saying that although they are usually deeply involved as advisors in all important investigations, there are few exceptions to the rule that they do *not* possess either accident investigation staff or an air safety department.

3.4. THE AIRCRAFT INSURER

The leading aviation insurance interests in the U.S.A. and the U.K. possess full-time investigating staff who usually also act as aviation claims adjusters. In the rest of the world, frequent use is made of resident aeronautical consultants retained either permanently, or called in from time to time as the need arises.

It is never the function of insurance investigations to supplant state investigations, operator's or manufacturer's investigations; but it is important to realise that there are many circumstances in which insurance investigations are the only serious investigations made:

(*a*) When no state investigations are made and the operator does not possess specialised investigators.

(*b*) When both the state and the operator's investigators are either non-existent or inexperienced.

It is pertinent to add a few words on the special objects of insurance investigations:

If insurance investigations do not supplant other investigations it may reasonably be asked why, except in the foregoing conditions (*a*) and (*b*), is it necessary to conduct such investigations? The need arises in two very practical and quite separate ways:

1. Insurance indemnities are a means of reducing the financial losses which inevitably arise from accidents. Hence the insured's first requirement is a prompt payment of whatever may be due. The insurer cannot pay until he is certain (*i*) that the reported accident represents the risk insured, and (*ii*) that the amount of loss is ascertained. To answer (*i*), the insurer must have an immediate, accurate (but not necessarily detailed) knowledge of why the loss was sustained and he must compare this with the particular policy conditions. The insurer could, of course, await the results of official investigations which may or may not be made public. For a variety of reasons this can rarely be done in under six months and the insured cannot usually wait that long for financial assistance. Therefore the insurer must dispatch his own investigator to make a rapid appraisal of the circumstances, always in close collaboration with other investigations in progress. By this means it is usually possible to be certain within 48 hrs. of an occurrence (using a specialised investigator) whether the actual accident represents a risk insured. The amount of loss is ascertained relatively easily.
2. Like the State, the operator, the manufacturer and the air transport user, the insurer must know whether the particular accident is likely to recur. The insurer needs this knowledge in order to assess his continuing and future risks. Hence in addition to the rapid, accurate appraisal required to establish his particular liability, the insurer must also analyse the *details* of the accident and follow carefully all other investigations and any ensuing action such as modifications. In short, just as it is the aim of "ideal" investigation to improve the level of air safety, so it is the aim of insurance investigation to estimate what this altered level will be.

4. Which Accidents are Investigated?

An accident must possess certain characteristics before it merits investigation by any of the agencies described. It will be the purpose of this Section to outline these distinguishing characteristics.

4.1. GENERAL

There are many countries which have not either ratified or adhered to the I.C.A.O. Convention of 1944[11]. Most of these exceptions are represented by the U.S.S.R. and U.S.S.R.-dominated states.

Of those states which have ratified the I.C.A.O. Convention there are many which have either not implemented, or differ in detail from, the provisions of Annex 13[9] concerning accident inquiry.

Information on "non-I.C.A.O." states is not readily available. The essential characteristics of any accident/incident required before investigation takes place cannot be summarised simply.

4.2. THE I.C.A.O. "CONVENTION STATES"

Those states which have ratified or adhered to the Chicago Convention of 1944 achieved a remarkable degree of uniformity in spite of widely differing individual legal systems.

The contracting states agreed that the state in which an accident occurs should institute the inquiry and for this purpose the accident must involve "death or serious injury" OR indicate "serious technical defect in the aircraft or air navigation facilities" (Article 26)[11].

Observe that this requirement is wide enough to include incidents where no one is hurt and no damage is done. But this definition does not make mention of either property or aircraft damage, nor does it specifically require that serious personnel errors ought to be investigated. Hence, for example, the following accident is not captured by the definition: Due to crew error the fuel system is mismanaged resulting in a power failure at take-off, the aircraft runs off the runway severely damaging itself and nearby property, but injuring no one. This need not be investigated by the State of Occurrence unless the fact that the fuel system was capable of mismanagment is construed as a technical defect in the aircraft. *It would require an investigation to ascertain this.*

4.3. THE I.C.A.O. "ANNEX 13 STATES"

It was not intended that Article 26 of the Convention should be the limit of agreed procedure between the states and consequently a special Annex to the Convention (No. 13)[9] was drawn up elaborating a more detailed procedure, but only for accidents involving serious injuries, serious damage, and so on.

Those states which have not dissented from Annex 13 have agreed upon a definition for an accident which requires inquiry. An accident is

"An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked in which

(*a*) any person suffers death or serious injury as a result of being in or upon the aircraft or by direct contact with the aircraft or anything attached thereto, OR

(*b*) the aircraft receives substantial damage."

In contrast to Article 26 of the Convention, this definition intentionally excludes incidents and theoretically would exclude those accidents in which only slight aircraft damage is involved, although those on board (or other persons) may have been exposed to the gravest danger. In practice it is not usually possible to

determine whether an accident comes within the definition without some sort of preliminary investigation and hence the definition tends to be more liberally interpreted than its defective wording might suggest.

Neither Annex 13 nor any other Annex to the Convention places any onus on an aircraft owner or operator to report accidents to the State of Occurrence. It is rarely possible to conceal the occurrence of an accident, but as long as reportable accidents are defined in terms of damage or injuries, rather than a potential threat to human life, there will exist a category of occurrences whose magnitude and importance remains unknown because it is unexplored.

Finally it may be said that although existing I.C.A.O. procedures do not ensure the investigation of all incidents/accidents of importance to air safety, individual states often attempt to spread the net wider with their own legislation.

In the United Kingdom, for example, the definition of a *notifiable* accident follows the lines of Annex 13, but an accident (for the purposes of outlining the rules for the investigation of accidents) is defined as

"Any fortuitous or unexpected event by which the safety of an aircraft or any person is threatened."[7]

Hence the reporting of incidents is on a voluntary basis and that seems generally to be the case in those states which are active in civil aviation.

4.4. THE AIRCRAFT OPERATOR

The leading airlines investigate all their own accidents, whether investigated by the state or not. The definition of a reportable incident/accident is usually commendably wide within the company and this results in a rich harvest of useful investigations. Unless outside agencies are involved in these investigations, the results are rarely circulated outside company doors. (Members of the International Air Transport Association have a system of accident information interchange and I.C.A.O. has begun the circulation of Accident Digests based on State reports. The American Flight Safety Foundation circulates data based on voluntary reports from contributors.)

Those operators who cannot afford the investigating machinery of the airlines often have no set procedure for investigation. The accidents which are not investigated by the state are often not subject to any serious investigation at all. The procedure adopted by a conscientious small operator may call for any one or all of the following:

(*a*) Suspected technical defects to be investigated by the aircraft manufacturer.
(*b*) Personnel errors to be remedied by disciplinary action and training.
(*c*) External assistance in investigation (*e.g.* the State or their insurers).

There are fortunately very few operators who do not consistently use at least one of these procedures.

4.5. THE AIRCRAFT MANUFACTURER (OR DESIGNER)

Manufacturers or designers, for reasons mentioned in the previous Section, do not conduct accident or incident investigations although they may be involved as technical advisors in all important state or operators' investigations. Wherever there is a suggestion of an aircraft defect, technical investigations are instituted. But if the defect is not reported by their own service engineers, and official notification is not received by some other means, a manufacturer can often remain in ignorance not only of accidents, but also of defects occurring well away from the factory[14].

4.6. THE AIRCRAFT INSURER

An insurer is notified only of those accidents likely to result in a claim. This means that damage must have occurred and the costs of repair are likely to exceed the appropriate "first loss" which is borne by the insured. This "excess" may vary from £20 for a small aircraft to £3,000 for a large aircraft: costs in excess of this result in a claim.

Sometimes an accident which ought to result in a claim is not notified, either to avoid unwelcome investigation or to preserve any financial bonus for a claim-free year.

Probable claims which are notified are then only investigated if the costs are likely to be high, or the circumstances call for clarification.

Insurers do not, therefore, investigate any *incidents*, while accidents are sometimes not investigated for any one of the following reasons

(*a*) No claim is notified.
(*b*) The cost of investigation is high compared to the probable claim.
(*c*) The circumstances appear trivial.

Since the cost of claims is tending to increase rapidly and civil aviation is expanding, insurers tend to investigate more and more accidents.

5. How are Accidents Investigated?

It is now appropriate to describe the methods and problems of current practical investigation. Due to the variety, in detail, of any one practical investigation it is not possible to do more than generalise the methods of collecting and analysing data. This will be done in skeleton form for two broad categories of accident:

1. A serious accident involving an investigation by an I.C.A.O. State of Occurrence with full participation accorded to the State of Registry.
2. An incident investigated by a small operator.

Practical investigation has a wide range of complexity. At one end of the scale there may be a major airline disaster which is front-page news for two or three days all over the world. The scene of the accident is visited by several dozen officials; investigation takes many months; an official report is issued one year later; court cases are fought for several years afterwards and the final bill for everything may be well over £1 million.

At the other end of the scale, a training aircraft taxies into a hangar door. It is not reported anywhere; investigation consists simply of the instructor asking, "How did you do it?' and the answer, "I thought the door was open." Total costs may be £15.

5.1. STATE INVESTIGATION OF A SERIOUS ACCIDENT

Notification of the accident to the State of

Occurrence is followed by this State's notification to the State of Registry including an invitation to participate in the inquiry.

The importance of a prompt examination of the accident site is widely recognised. Hence, notification of a major accident is the signal for the start of a polite race to the accident scene by representatives of

the State of Occurrence
the State of Registry
the Operator
the Manufacturers
and the Insurers.

All interested bodies recognise that wreckage may only be examined by permission of the investigating authority—the State of Occurrence. The rule is never violated.

The task of the chief investigating official of the State of Occurrence assigned to the accident (hereinafter referred to simply as the investigator) is first to recognise the credentials of other officials assigned to him—including foreign representatives—and then plan his own work and the division of responsibilities within his (usually) large investigating team. This may be done either before or immediately after a first visit to the scene of the accident and wreckage.

Thereafter the investigator's task is one of co-ordination of effort and analysis of day-to-day results. The investigating officials (the State of Occurrence investigator and the State of Registry accredited representative) plan each day's work, often share such tasks as taking statements and may sometimes hold their daily conferences with a full audience of all interested bodies (representatives of the Operator, the Manufacturers and the Insurers). Investigation proceeds not by a series of inspired brain-waves, but by patient accumulation of systematic data:

(*a*) The wreckage is examined minutely by an expert in wreckage analysis, assisted by operator's and manufacturer's representatives who are intimately familiar with every inch of their machine.
Permanent records are made of the appearance and location of every item.

(*b*) Statements are taken from eye-witnesses, operational staff, meteorological staff, air traffic controllers and indeed any persons who can possibly illuminate the detailed circumstances of the accident under investigation.

(*c*) Data is also accumulated on the procedures adopted for accident notification, alerting and operation of search, rescue and fire services.
NB.—Search, rescue and fire services all over the world are not universally aware that it is important always to try to record the exact locations and attitudes of bodies, and to disturb wreckage as little as possible when it is clear that there are no lives to be saved. Ignorance of this has often impeded subsequent investigations.

Once the accumulation of data on-site has finished, a preliminary analysis of evidence will begin which is a more formal procedure, usually confined to investigating officials. Further experts may be called to interpret various aspects of the data collected and it is in this process that the potential strength or weakness of an investigator is revealed. If he can co-ordinate and analyse accurately the information and expert testimony before him, his investigation will be invaluable, but if analysis and co-ordination is his weak point, then the most comprehensive data and the most eminent experts will be wasted.

No investigator can be familiar with every aspect of an accident which he is investigating and therefore he must necessarily seek a variety of expert advice in the interpretation of the data before him. That is why the *preliminary* analysis of evidence is so important—it hinges on the analytical and co-ordinating skill of one, or perhaps two, investigating officials. When they have made their report, summarised their findings and drawn their conclusions, the report is passed on for further action. This may be to decide that:

(*a*) further investigation is unnecessary;
(*b*) a few additional points may require clarification;
(*c*) the report may or may not be published;
(*d*) the report is suitable for action by a department which will undertake to follow-up all the lessons to be learnt from the accident;
or (*e*) a public inquiry must be held.

Note that the key to all future action is preliminary analysis by the working investigators. It is rare that new facts are revealed, or new lines of enquiry pursued after the original investigators have concluded their investigation and reported thereon. Even public inquiries, except on very rare occasions, will fail to reveal new facts although they may give greater insight into responsibilities involved in the accident than could have been determined by investigations in private.

Both the preliminary analysis of evidence by the on-site investigators and the final analysis by the state investigation department (or public inquiry) tend to be similar in method. It is therefore worth while noting briefly the general method which is adopted and noting also the characteristic gaps in knowledge:

1. Evidence on all aspects of the accident is collected and either certified to be true in written form or obtained as oral testimony.
2. This evidence is then grouped under various heading such as
   Airworthiness of Aircraft
   Competence of Crew
   Circumstances of the Accident
   Examination of Wreckage
   Operator's regulations concerning features of the accident
   State regulations.
3. A connected history in relation to the accident under each heading, based on the evidence, is prepared.
4. Expert opinion may be sought concerning
   (*a*) the interpretation of evidence,
   (*b*) the correctness, or otherwise, of the actions of all persons connected with the circumstances of the accident.

Now the transference of opinion or information from an expert witness to an investigator or the head of a public inquiry, is a delicate and subtle process calling for outstandingly clear thought on both sides. The expert opinion may depend on extensive laboratory tests or it may simply depend on the peculiar knowledge and experience of the expert.

Not every State of Occurrence possesses such facilities or experts, nor can every such state afford to pay for foreign facilities or experts and indeed, not every State of Occurrence has enough interest in aircraft accidents to wish to incur such expense. There is provision in I.C.A.O. Annex 13 for a complete or partial delegation of all this work to the State of Registry. It is always assumed that the State of Registry has the deepest interest in a particular accident and hence, should possess all the necessary facilities and experts for a full-scale investigation.

A major accident usually requires expensive facilities for elaborate investigation and therefore in the end this usually has to depend on the *existing* facilities of the State of Registry. This is an important point which must always be borne in mind. The State of Occurrence can please itself how its responsibilities for an inquiry under I.C.A.O. Annex 13 are discharged, because the Annex does not define either the *nature* or the *scope* of an inquiry (in fact the Standards and Recommended Practices of Annex 13 "Aircraft Accident Inquiry" are really more appropriate for facilitating the process which the Foreword to the Annex carefully distinguishes as an "investigation").

Assuming that all necessary facilities for investigation exist, it must next be made clear that in the most serious disasters there is a preponderance of reliable mechanical evidence over reliable human evidence.

It is in the nature of things that in most accidents there is wreckage available for inspection. There are laboratories for the examination of materials and moreover, the past half-century has been devoted to the study of aviation structures and mechanisms. There is usually, therefore, a very good chance that the mechanical features of an accident are fully explored. (*See*, for instance, Refs. 15, 16 and 17.) It is often possible to produce a highly probable sequence of mechanical and structural events. But it is also in the nature of things that the most serious accidents are sufficient to kill all on board. There is no human data for analysis. Until recently there were no recordings of air-ground-air conversations. It is rarely possible to reconstruct even a possible sequence of human events, particularly when radio contact has inexplicably ceased.

This is the biggest practical difficulty facing the most competent investigators—the great gulf between the exploration of the mechanical features and the human features of an accident. A curious result arises from this experience.

Investigators in all countries are accustomed to such a full exploration of mechanical failures—it is so easy to follow a mechanical sequence—that wherever it is possible to ascertain the existence of a human failure, their thinking is exactly the same.

For example, if an undercarriage fails to descend because of faulty design, it is easy to investigate and the remedy lies at hand—redesign and it will not occur again. By analogy it is often thought that if the undercarriage fails to descend because the co-pilot forgot to do it or put down extra flap instead, then the investigation is similarly easy—"personnel error" and a recurrence may be averted by admonition, disciplinary action or even an improved training programme. Many investigators cease at this point. The personnel error has been detected, the investigation is ended. Yet the answer is far too simple to explain or control so complex a mechanism as a human being.

The investigator has many competent advisors to tell him how the undercarriage should be designed, but he has no one to advise him on the correct design of cockpit controls and procedures so as to take account of average pilot capabilities. There is no one who could assert to him that the co-pilot was fatigued after doing a long flight's navigation at night, dazzled by occasional glances at the approach lights or "mesmerised" by steady lights on the control panel, so that, in plain language, he was vacantly dreaming when he should have put the undercarriage down. The all-too-frequent analysis is, "the co-pilot was at fault, there is no more to be said."

Those experts whom the investigator calls upon for advice are often little adapted to giving a clear idea of what should be possible for the averagely competent human being in any sphere. The pilots he consults are Chief Pilots or Test Pilots; the meteorologists are Chief Meteorologists and the traffic control officers are Chief Traffic Control Officers. But if a material failure is involved, the Chief Designer or Chief Stressman is at hand to assert perhaps that the structure was designed within the most probable loading envelope and the actual failure stress was within statistically acceptable limits for the type of materials under consideration. There is no one who can make similarly credible statements on behalf of a flight engineer or pilot.

The foregoing are some of the problems facing modern investigators. The problems are rarely solved except approximately by a variety of compromises.

A serious accident under investigation by the State of Occurrence assumes an international importance and hence the findings of the official inquiry are usually published. The report is prepared in consultation with the State of Registry, who are not necessarily bound to accept the results. The State of Registry need publish a report only if required to by local regulations.

Publication of recommendations and the implementation of the results of an inquiry is always a delicate matter when the State of Occurrence does not coincide with the State of Registry. The reason is that recommendations may often involve a great many things for action by the State of Registry. Implementation of all things which may be found necessary as a result of an accident is never easy when the investigation has taken place many thousands of miles from the country where implementation has to be discussed and carried into effect. A great deal then rests on the calibre of the State of Registry accredited representative at the inquiry—he has to be able to bring back a great deal more accurate

and detailed information than any published report would suggest.

5.2. SMALL OPERATOR'S INVESTIGATION OF AN INCIDENT

It will be recalled that an incident is any unexpected event arising out of aircraft operating which might threaten harm to any person.

For the sake of discussion, a small operator is one with, say, less than ten transport aircraft including not more than two or three items of four-engined equipment. There will be no specialised investigating staff and the investigation of an incident will depend entirely on the circumstances. For example, if an aircraft is involved in a "near-miss" collision, then, provided that the pilot did not think he was culpably involved, he would register a complaint with the local aviation authority and his company. If the pilot thought he might be culpably involved the chances are that he might not even report the matter to his own company and they would only hear of it if investigations were started elsewhere. The magnitude of this problem is unknown because it is unexplored.

Technical defects in the aircraft which create an incident are likely to be fully investigated, first by the operator's engineers and then by manufacturer's representatives. This is the only category of incident of which the small operator is at all likely

(*a*) to receive notification,
(*b*) to be able to investigate.

There is evidence that with the large airlines, particularly national airlines, the problem of voluntary incident reporting is not so great. Probably there are at least two good reasons:

1. There are opportunities for a greater sense of pride in the organisation and a consequently enhanced realisation of responsibility.
2. The organisation is so much larger that the chances of error or misjudgment on the part of a single person remaining undetected are decreased.

Details of operators' incident investigations are, with very rare exceptions, never published although they are sometimes communicated privately to State departments administering aviation or airworthiness.

For major operators, there is an interchange of information between I.A.T.A. members, while for general purposes the American Flight Safety Foundation arranges for the circulation of voluntarily reported incidents.

6. Results of Current Investigation Procedures

The general characteristics of current investigating procedures have already been described, but before considering some accident statistics a brief recapitulation will be made of the salient features of modern investigation, with a deliberate emphasis on some of the least satisfactory points:

1. In all countries of the world the individual state has the best statutory opportunity to investigate all accidents and incidents.
2. For a variety of reasons, most states rarely have the opportunity to investigate *incidents* except where they occur on a gross scale.
3. The operator, who always has the most pressing reasons for learning quickly the facts of other accidents besides his own, is not in a position to acquire such information easily.
4. Manufacturers, with very rare exceptions, do not investigate accidents although they may often be concerned as advisors. Nor can they be aware of the necessity for possible design modifications as a result of investigations unless other agencies make suitable recommendations.
5. Insurers only investigate costly accidents or accidents which require clarification in relation to their policy conditions.
6. States need only investigate accidents to comply with state necessities, not necessarily for the purpose of improving air safety.
7. Only a few states have the facilities for full-scale investigations and not all of these are prepared to spend large sums of money on accident investigations which go beyond a determination of the immediate cause of an accident.
8. Not all states follow I.C.A.O. practices with respect to accident investigation.
9. There is a considerable difference between the requirements of Article 26 of the Convention and Annex 13 on the definition of an accident for the purposes of Inquiry.
10. Annex 13 does not require an operator to notify accidents, nor is the purpose and scope of an inquiry defined and there is no requirement for the publication of results other than to immediately interested parties.
11. There is a tendency in investigation work to separate the functions of collecting data, analysing data, preparing recommendations and implementing the results.
12. In all investigations, not only is there usually a preponderance of mechanical data over human data, but the investigating apparatus tends to favour a solution of the mechanical problems involved to the detriment of any human factors which may be involved.
13. Hence current investigation procedures differ from the "ideal" investigation of Sections 1 and 2 in the following respects:
    (*i*) Incidents are not universally reported.
    (*ii*) The State is the only agency with the authority and the facilities for full-scale investigations.
    (*iii*) The State agencies do not investigate all incidents/accidents and those that are investigated may be taken only to the point of ascertaining the direct cause.
    (*iv*) The operators (who should have rapid, accurate information from *all* accidents) and the manufacturers (who must execute and design changes necessary) are not in

the best position either to receive information or (except with an operator's *own* accidents) pursue their own enquiries.

(*v*) Data analysis and the formulation of recommendations are functions often separated both from the work of investigation and from the implementation of results.

(*vi*) There are few facilities for the exploration of the human features of an accident as opposed to the mechanical features.

(*vii*) It is not the universal aim of all investigations " to provide scientifically valid data which shall assist in preventing future similar occurrences *and* generally contribute to safer aviation."

(*viii*) Publication of useful results to as wide an aviation community as possible is only achieved in a proportion of accidents/incidents notified.

Data from all over the world suggests that as a result of all these factors, investigation does not always succeed in " preventing future similar occurrences " nor does it always " generally contribute to safer aviation." In order to demonstrate this honestly it would be necessary to compare in detail the accident data published by different countries and note the correlation of trends, and so on. Unfortunately that is not practicable in this paper for two main reasons:

(*a*) There are too few countries which publish such data,

(*b*) It might be an embarrassing process to countries singled out for attention.

It is hoped that the following two examples will be unidentifiable both as to country of origin and type of aircraft:

(*i*) Failure to prevent future similar occurrences in the same country.

" In the early history of a transport aircraft a series of accidents demonstrated that pilots had failed to judge approach height accurately from the cockpit.

" Then an accident occurred which was attributable to the fact that the pilot did not appreciate the attitude of the aircraft at take-off.

" Not until a fatal accident occurred from the same cause was it realised that there was no good means whereby the average pilot could gauge height or attitude accurately from the cockpit."

It is clear that early accidents tended to be dismissed as errors of judgment: while in the first take-off accident there could have been no extended efforts to analyse and reconstruct the human sequence of events.

(*ii*) Failure to contribute generally to safe aviation.

" A small transport aircraft approaching to land at a major airport was caught by the turbulence of a large transport aircraft. The small aircraft hit the ground out of control.

" Very shortly afterwards, in another country an almost identical incident occurred."

Either the existence of the first accident was not known in the second country or its general significance was not realised.

These are two examples from many which could have been quoted. It is apparent that fundamentally the difficulties are (as in all the sciences) those of dissemination of information.

Data analysers and those concerned with the design of recommendations often lack information on the availability of solutions to design or training problems.

Operators and manufacturers lack information on the salient features of other people's accidents which might be reproducible in their own aircraft and operations.

The regrettable thing is that a great deal of the required data does exist but is not either readily available or in assimilable form for use by interested parties. Some ways in which the situation might be improved are suggested in Section 8.

An improvement in air safety ought to be a direct or indirect result of accident investigations, not only for the moral value of such a process, but also for the economic value. If air travel could remain in the public eye as a demonstrably safer form of travel than rail or boat for as long as ten years, undoubtedly the air travelling public would increase. For this purpose the number of passenger fatalities per 100 million passenger-miles may be useful for publicity purposes, as was pointed out by Mr. Tye[5], but it is of little value if the improvement of air safety is being studied. Mr. Tye's analysis of the uses and significance of accident statistics is probably the only balanced view in print. (There is, incidentally, a marked lack of useful statistics on a world-wide basis for the serious student of accident causes.) He was able to demonstrate that in a comparable post-war period, lack of airworthiness accounted for only 9 per cent. of U.K. transport accidents (1946-1951) and 29 per cent. of U.S.A. transport accidents (1947-1949). The U.K. figure did not change a great deal in 1952 (for *all* operations) but in the U.S.A. also over the complete period 1946-1952, the percentage of all air-carrier accidents which has a primary cause somewhere on the aircraft has remained at 29 per cent., while in 1952 itself the figure was nearer 23 per cent.[12]. The order of difference between the U.K. and U.S.A. is a factor of two and this is probably due to the larger number of different new types entering service in the U.S.A. as compared with the U.K.

Both figures reflect a minority of accidents which can be primarily blamed on the aircraft itself and this is in accordance with the facts, noted above, that in any investigation there is a good chance that the mechanical features will be fully explored.

Before proceeding further it is well to note that the statistical significance of U.S.A. figures cannot be approached by any other country. For example, in the U.K. in 1952 there were 79 notifiable accidents *of all kinds*, whereas in the U.S.A. in 1952 there were 104 air-carrier accidents alone, while the non-air-carrier total was 3,657.

Mr. Tye's studies show the following comparison of air crew errors in air transport operations:

U.K.	U.S.A.
1946-1951 66 per cent.	1947-1949 54 per cent.
For 1952 the figures are:	
U.K. (all operations except gliders and helicopters)	U.S.A. (air-carriers)
Pilot or other crew member 77 per cent	38 per cent. (pilot error)[12]

Part of the reason why the 1952 U.K. figure for pilot error is so much higher than the U.S.A. figure is that the result is obtained over *all* operations as opposed to air-carrier operations. In both countries (and indeed in all countries) pilot or personnel error makes the biggest single contribution to accident causes, and is always an even larger factor in private flying accidents.

The irresistible conclusion is that generally the most dramatic improvements in air safety will be obtained by seeking a reduction in the incidence of personnel errors and an amelioration of the results of personnel errors. The exploration of airworthiness in terms of functional reliability seems to be a well-established process. (In passing, it may be noted that "lack of performance" appears very rarely as an accident cause and yet "performance" seems to be the primary target for all discussions on airworthiness, particularly at an international level.)

In the next section an attempt will be made to assist investigators in their study of human errors. Large-scale investigations of the human factor in aircraft accidents have yielded useful results in the U.S.A.F.[29, 30].

7. Human Failure is Normal

7.1. INTRODUCTION

Human beings are allowed to make mistakes except if they are engaged in aviation—particularly civil aviation. This attitude of mind is so widespread that it is probably the biggest single impediment to any understanding of the human factor in aircraft accidents. There are few people to deny that the human factor is important—for example, it was noted in this JOURNAL as long ago as 1914[2] and as recently as 1951[6]—and while the years have brought forth a great deal of factual data on the behaviour of human beings there has been very little corresponding assimilation of this information.

It will be the purpose of this section to place human error in some kind of perspective. Most works on this subject do little to correct the layman's notion that such studies are concerned with abnormal or extreme effects in human behaviour (*see*, for example, Group Captain Newton's paper[6] or Chapter 9 in the I.C.A.O. Manual of Aircraft Accident Investigation[10]). In what follows the "*normality*" of human error will be emphasised so that investigators may find it easier to regard investigations into the human factor as normal, to be encouraged as routine. In consequence it is hoped that they will begin to ask for more and more data on the human machine to assist in their work.

The problem is complicated by the fact that there is probably only a handful of men who are specialists in this branch of knowledge. There are medical men, psychologists, anthropometrists and the rest who possess a great deal of the data on the one side and there are designers, operators and investigators on the other who would like to use the data. There are very few in between who can co-ordinate and translate the scientific data into useful engineering data for incorporation into the aviation industry. The author is aware of very few serious projects for this purpose which have been published[17, 18]. A consequence of the general failure to appreciate that this gap exists results in the scientist's surprise at the engineer's ignorance and the industry's suspicion of the value of such data as does exist.

This section will not attempt even to outline that branch of science which has been called "human engineering," *i.e.* a knowledge of the structure, performance, characteristics and capabilities of normal men in a form suitable for engineering use. The notes which follow are designed to assist in correcting widespread misconceptions of the nature and significance of human error.

7.2. THE PREJUDICE AGAINST ERROR

We all suffer from prejudice whenever we discern error in someone else, even though error in human actions has been recognised and accepted since time immemorial. In everyday language, error amounts to the tendency to make mistakes and is usually ascribed loosely to "carelessness," "poor memory," "fatigue," "day-dreaming," and so on. More precisely, error, whether it be human or mechanical, may be measured as a deviation from some ideal performance.

Also since time immemorial we have been used to the idea that usually some kind of superior intelligence is required to be able to perceive another person's errors. For example, a detective may legitimately be regarded as the intellectual superior of a criminal whose errors he has uncovered. But unfortunately there also persists a fallacious corollary which runs:

"Because an observer often requires a considerable intellectual effort to detect an error-action, therefore the error-actor (who performs the error-action) is of inferior intellect."

This is probably true where the activity observed involves pure intellectual judgments, but it is not necessarily true when the activity is that of operating a machine by means of acquired skills.

An aircraft accident investigator may detect an error-action in the course of his investigations. The error-actor might be an experienced professional pilot or an equally well-qualified air traffic control officer. Even if there are no mitigating circumstances the investigator must beware of labelling the error-action as "unintelligent," "foolish," "stupid," and so on—all these words bear a high emotional charge born of the unconscious prejudice against error. This type of thinking contributes nothing to an understanding of the causes of human error and hinders any advance in air safety.

If the investigator avoids this trap and passes on his factual report for a higher authority or management to consider, this unjustifiable prejudice is liable to re-appear in a more pronounced form. Even the error-actors realise this.

There are three main reasons why civil air transport

produces a strength of prejudice against error not experienced by any other form of transport:

(*a*) Flying is a relatively new form of transport and the attitude of those who sit in judgment on errors is inevitably controlled by those living pioneers to whom air transport has been a personal triumph. This may amount to a reluctance to admit that human errors still occur in spite of a lifetime's efforts.

(*b*) Due to the impetus of two world wars and the value of aircraft as tactical and strategic instruments, aviation has been subjected to highly concentrated research and development. In accident investigation it is therefore possible to focus considerable intellectual capacity on to the perception of human error. By comparison, the error-action itself, bared of all circumstantial excrescences, is apt to appear "thoughtless," "unintelligent," "stupid," and so on.

(*c*) An aircraft only remains airborne by maintaining a minimum relative velocity of its aerofoils through the air. Moreover, the usual combination of speed and altitude gives the aircraft a high potential and kinetic energy available for destruction against the static earth. Hence, not only does the aircraft demand a low degree of error in its handling, but those errors which accumulate to form accidents will almost invariably have very serious results.

This deep prejudice against error in aviation is so widespread, and the reasons for it so little appreciated, that error is regarded as a shameful thing to be hidden instead of being brought into the open, examined and eradicated if possible or the results of error rendered harmless.

It is this prejudice which makes incident reporting so difficult. It is the reason why the full details of an accident often become the best-kept secrets of a government or an operator. Of course an operator has every reason for withholding accident details from the lay public, but there can be no excuse for withholding details from the aviation community when a knowledge of "shameful" errors could materially assist in preventing future similar occurrences.

Error is always a human failure to conform to ideal performance. It should always be regarded in the same unemotional light as material failure and subject to the same rigorous examination.

7.3. WHAT IS HUMAN FAILURE?

At the Air Safety Conference in 1949[1], Mr. J. D. North said, "...the problem of safety in aviation is fundamentally a problem of human behaviour." Expanding on this it is easy to agree that:

"All aircraft, their ancillary equipment, navigation aids and ground equipment are designed, built and operated by human beings, and the human factor must, therefore, in principle be either a primary or a contributory cause of all aircraft accidents"[10].

The examination of prejudice against error led to the conclusion that human failure ought to be the subject of serious investigations and no greater stigma ought to be attached to one kind of failure rather than to another. Hence it ought to be possible to give equally searching scrutiny to:

HUMAN FAILURES IN DESIGN
IN REGULATIONS
IN MAINTENANCE
IN NAVIGATION
IN AIR TRAFFIC CONTROL
IN AIRMANSHIP, and so on.

Grave design errors are fortunately rare enough to excite no great vehemence when they are discovered. Because design work proceeds in calm conditions with opportunity for reflection and consultation, the student of accident investigation might be excused for drawing two conclusions:

(*i*) If errors can occur when there is every opportunity for meditation then it is little wonder that errors can occur during the stress of flying.

(*ii*) Design errors should receive more serious strictures than air crew errors once responsibilities have been analysed.

In practice, the tendency is to reverse the "amateur" conclusion (*ii*) above. Hence the accident investigator may find two definitions useful to bear in mind at all stages:

A MATERIAL (or MECHANICAL, ELECTRICAL, and so on) FAILURE represents a gap in our knowledge and control of the loads (or functions) to be encountered or a gap in our knowledge and control of the ability of the load-carrier (or system) to resist known loads (or perform known functions), or a combination of both types of ignorance.

A HUMAN FAILURE represents a gap in our knowledge and control of the situations to be encountered, or a gap in our knowledge and control of the ability of the individual to cope with known situations, or a combination of both.

The investigator of the human factor in aircraft accidents cannot afford to rest until he has got as near as he can to reconstructing

(*a*) The particular accident-situation,

(*b*) The ability of the particular individual in the particular situation.

7.4. HOW TO EXPLORE THE HUMAN FAILURE

When the conscientious investigator has made every possible effort to reconstruct every detail of the physical situation in which an error was committed and he has reconstructed as far as possible the physical and mental history of the individual (if necessary throughout the day leading to the error-action) what then? How can he uncover the cause of the error-action?

The error may be either a:

FAILURE TO DO SOMETHING
or a
FAILURE TO DO SOMETHING CORRECTLY.

Both of these are conveniently summarised as "deviations from an ideal performance = error-action"*.

*Error-actions are not necessarily single acts. The term "error-action" may cover a sequence of acts or a complete pattern of behaviour.

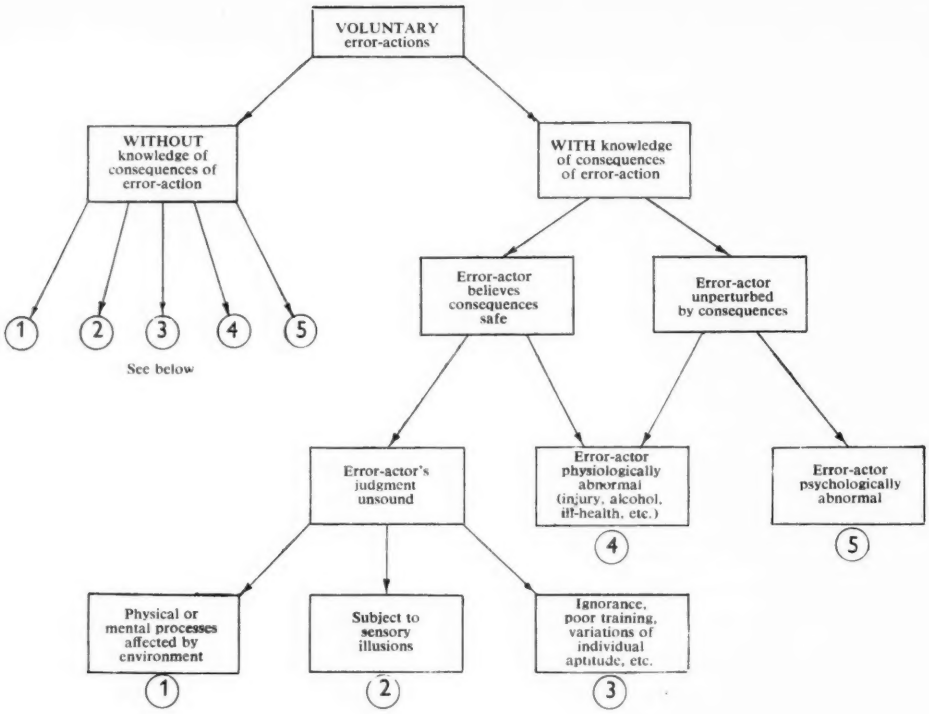

FIGURE 1. Approximate analysis of voluntary error-action.

Error-actions may be either VOLUNTARY (meaning that the individual can decide not to do the particular action) or INVOLUNTARY (meaning that the individual cannot consciously restrain himself from doing the particular action). The approximate causes of Voluntary and Involuntary errors are set out in Figs. 1 and 2 and may be summarised as follows:

APPROXIMATE CAUSES OF ERROR ACTIONS
(Nearly all headings overlap)

1. VOLUNTARY
   - (*i*) Physical or mental processes affected by environment.
   - (*ii*) Subject to sensory illusions.
   - (*iii*) Ignorance, poor training, variations of individual aptitude, and so on.
   - (*iv*) Physiologically or psychologically abnormal.

2. INVOLUNTARY
   - (*i*) Physical or mental processes affected by environment.
   - (*ii*) Subject to sensory illusions.
   - (*iii*) Acted upon by external forces.
   - (*iv*) Physiologically or psychologically abnormal.

It will be observed that only under ONE heading in either VOLUNTARY or INVOLUNTARY error-actions is the cause attributable to ABNORMAL conditions of the individual. Moreover, it will be seen that three of the headings are identical for the approximate causes of both types of error-actions. The practical accident investigator will next need to know where he can find information under all these headings. The general answer is that in the U.K. advice is best sought from the R.A.F. Institute of Aviation Medicine at Farnborough and in the U.S.A. from The Daniel and Florence Guggenheim Aviation Safety Center at Cornell University. These are only two of many research centres which have access to relevant scientific data and they possess experts who are experienced in translating the scientific results into information useful for the practical investigator or designer.

Available publications are best studied by reference to the series of annual surveys published by The Daniel and Florence Guggenheim Aviation Safety Center[19]. The most outstanding contribution available so far is undoubtedly the "Handbook of Human Engineering Data" produced by the U.S. Navy Special Devices Center[18]. It deserves wide circulation.

Finally a few notes on the sort of information which can be expected under the various headings previously referred to:

(*i*) *Physical or Mental Processes Affected by Environment*

This will include effects of noise, vibration, fatigue, anoxia, heat, cold, ocular fascination, and so on[18-22].

(*ii*) *Subject to Sensory Illusions*

This will include optical, auditory and proprioceptive effects. Especially Refs. 19, 23 and 24.

(*iii*) VOLUNTARY—*Ignorance, Poor Training, Variations of Individual Aptitude, and so on*

The investigator will not require external assistance to determine whether ignorance of the correct action was the cause of an error, but he will require assistance to determine whether the amount or type of training was scientifically adequate for the process of learning. Some guidance is given in Ref. 19.

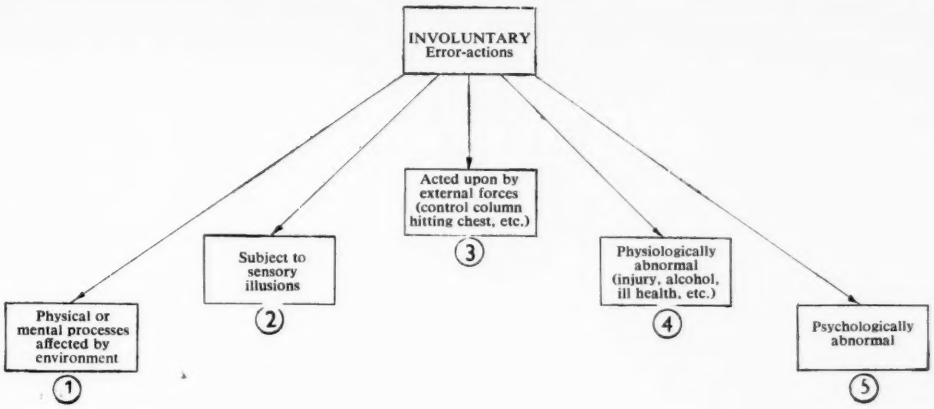

FIGURE 2. Approximate analysis of involuntary error-actions.

(*iv*) INVOLUNTARY—*Acted upon by External Forces*

Here again the investigator will not usually require external assistance to determine that, for example, control column movement was precipitated by pilot's seat slipping or the pilot was unable to reverse propellers after landing due to a flashlight laid behind the throttles[23]. But he will need to know how design might be altered to avoid these results or how procedures might be changed to avoid these situations.

(*v*) *Physiologically or Psychologically Abnormal*

This will include the effects of physical and mental illnesses, anxiety, heart ailments, and so on. *See* particularly Refs. 22 and 26.

In concluding this section it may be noted that although all the ideally required data on "human engineering" may not exist, an investigator would derive considerable benefit from utilising fully existing knowledge[25]. In this way his investigations will be able to deal more fundamentally with the problems of human behaviour associated with accidents and thus remedial action can be similarly at a more fundamental level. The way is then open to improvements in air safety.

But it should not be thought that the aim of these studies is the elimination of human error (deviations from ideal performance). That is impossible. There are three reasons for this:

(*i*) Human fallibility exhibits the characteristics of random occurrences.

(*ii*) Human beings will continue to deviate from any ideal performance from time to time because "ideal performance" must always be an arbitrary concept.

(*iii*) Most accident causes are linked with the *summation* of the effects of many small errors none of which *in itself* necessarily represents a significant deviation from ideal performance.

The most that studies of human behaviour can do for the safer operation of aircraft is as follows:

(*a*) Ensure that the individuals involved are properly selected and adequately trained for their jobs.

(*b*) Ensure that methods of work and the work-environment itself have little or no effect on the production of errors.

(*c*) Attempt to minimise or render safe the results of such errors or combinations of errors as may be reasonably predicted.

These three aims are attempted already—but adequate human engineering data will enable them to be put on a sound scientific basis.

It may perhaps appear that the human factor in aircraft accidents has been over-emphasised. On the contrary—it cannot be too strongly asserted that this factor will assume an ever-increasing importance in the future. Aviation is fortunately continuing to expand and is consequently drawing upon wider reserves of manpower to fill the posts arising. Men who might have been bank-clerks, farmers or marine engineers will become pilots, flight engineers and traffic control officers. Already there is a shortage of trained airline captains. The release of trained personnel from the Air Forces of the world produces men whose experience is diverging more widely from civil aviation day by day. Speeds and altitudes are increasing. Aircraft contain increasingly complex systems and controls. There will be no supermen to guide them and it is evident that a careful study of ordinary human capabilities in a variety of flight situations will be an essential for the future.

There are encouraging signs in recently-published accident reports from the C.A.B. in America and the M.C.A. in England, which suggest that a study of the human factors involved is becoming a more important part of accident investigations.

8. A New Approach to Investigation

It has been noted how the world-wide facilities for scientific investigation fall short of the ideal and "incidents" remain a poorly-explored territory. There is often a separation of functions between Investigation, Analysis and Implementation—a danger appreciated by a Congressional Committee investigating policy problems ". . . the functions of the former Air Safety Board . . . largely *degenerated* into conducting investigations following accidents . . ." (1943)[28].

It is clear that any new approach to investigation

must be integrated with the general effort to improve air safety by way of strengthening the link between the occurrence of an accident/incident and some resulting improvement in air safety.

Previous Sections have emphasised that the most dramatic results are to be obtained from exploring the human features of investigation. Unfortunately the facilities for doing this are restricted, such data as does exist is not widely known to investigators and, moreover, any exploration of human error is hindered by wide and deep-rooted prejudices.

A possible new approach to investigation which may gradually overcome most of these difficulties is suggested.

1. Establish, perhaps with the I.C.A.O. Regional network, two or three Safety Analysis Centres (say one for North and South America and one in Europe) with the following functions:
   (*a*) Receive and disseminate information of value to air safety to all who are prepared to pay for such a service within the regions.
   (*b*) Receive and disseminate information of value to investigators who would be nominated by individual investigating agencies.
   (*c*) Encourage and assist the aviation community to form a realistic air safety attitude. (In particular, human error must be removed from the realm of prejudice and exposed for scientific scrutiny. This will bring in its train a freer reporting and analysis of incidents.)
2. Investigators must play a key role in all three functions of:
   Investigation
   Analysis, and
   Implementation.
3. Investigators must learn to assimilate "human engineering data" just as they have learnt to use mechanical and other engineering data.
4. Establish a forum where accident investigation techniques and results can be discussed with the same vigour that is accorded to other branches of aeronautical science. (Perhaps in conjunction with 1 (*a*) and (*b*) above.)
5. More aircraft designing firms could usefully appoint "safety analysts," "safety engineers" or "investigators" who would share equal status with State and Operator's investigators during investigations and in receipt of useful information from the suggested Safety Analysis Centres.
6. "Safety Analysis," "Safety Engineering," or "Human Engineering" are suitable subjects for graduate and post-graduate engineering courses at universities and technical colleges.

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TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

Note on the Problem of an Infinite Wedge under a General Polynomial Law of Boundary Loading

by

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THIS NOTE gives the stress distribution in an infinite wedge subject to a general polynomial law of loading along either edge. The method used is that of Complex Potentials, the results of which may be summarised as follows:—

The stress combinations $\Theta = \overline{xx} + \overline{yy}$ and $\Phi = \overline{xx} - \overline{yy} + 2i\overline{xy}$ and the complex displacement $D = u + iv$ are given in terms of two complex potentials $\Omega(z)$ and $\omega(z)$ by the relations

$$2\Theta = \Omega'(z) + \overline{\Omega}'(\bar{z}) \quad . \quad . \quad . \quad (1)$$

$$-2\Phi = z\overline{\Omega}''(\bar{z}) + \overline{\omega}''(\bar{z}) \quad . \quad . \quad (2)$$

$$8\mu D = \kappa\Omega(z) - z\overline{\Omega}'(\bar{z}) - \overline{\omega}'(\bar{z}) \quad . \quad (3)$$

body forces being assumed absent and $\overline{pq}$ denoting the stress intensity across a face perpendicular to **p** and resolved in the direction **q**, for a body in a state of generalised plane stress, μ is Lamé's constant and κ is related to the modified Poisson's ratio σ, by the equation: $\kappa = 3 - 4\sigma$.

The boundary stresses $\overline{nn}$ and $\overline{ns}$ are also given subject to the above conditions by

$$\frac{\partial}{\partial s}\{\Omega(z) + z\overline{\Omega}'(\bar{z}) + \overline{\omega}'(\bar{z})\} = 4(\overline{nn} + i\overline{ns})\frac{\partial z}{\partial s} \quad . \quad . \quad . \quad . \quad (4)$$

The wedge is supposed of angle 2α so that the two edges are $\theta = \pm\alpha$ as in Fig. 1.

LOADING ALONG ONE EDGE OBEYING A LINEAR LAW

In this case

$$\overline{nn} = -(a + be^{-i\alpha}z), \quad \overline{ns} = -c,$$

a, b, c being constants, along the boundary

$$OP = z, \quad \theta = \alpha, \quad \text{and} \quad z = OP' = ze^{-2i\alpha};$$

and $\overline{nn} = \overline{ns} = 0$ along the boundary

$$OP' = z, \quad \theta = -\alpha, \quad \text{and} \quad z = OP = ze^{+2i\alpha}.$$

The boundary stress equation (4) now becomes

$$\Omega(z) + z\overline{\Omega}'(\bar{z}) + \overline{\omega}'(\bar{z}) = -4(\alpha + ic + \tfrac{1}{2}bze^{-i\alpha})z$$

along $\bar{z} = ze^{-2i\alpha}$

$$= 0 \quad \text{along} \quad \bar{z} = ze^{+2i\alpha}. \quad (5)$$

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Assuming complex potentials

$$\Omega(z) = Az + iBz\log z + (C - iG)z^2$$

$$\omega(z) = (E - iF)z^2 + (D - iH)z^3$$

(where all the constants are real), equation (5) gives

$$Az + iBz\log z + (C - iG)z^2 +$$

$$+ z[A - iB - iB(\log z - 2i\alpha) + 2(C + iG)z(\cos 2\alpha - -i\sin 2\alpha)] +$$

$$+ (E + iF)2z(\cos 2\alpha - i\sin 2\alpha) + 3(D + +iH)z^2(\cos 4\alpha - i\sin 4\alpha)$$

$$= -4[a + ic + \tfrac{1}{2}b(\cos\alpha - i\sin\alpha)z]z,$$

and a similar equation in which the signs of α and $\sin n\alpha$ are changed in the left hand side and the right hand side is equal to zero.

Equating coefficients and solving the resulting equations gives

$$A = -(a\sin 2\alpha + c\cos 2\alpha)/\sin 2\alpha;$$

$$B = 2(a\cos 2\alpha - c\sin 2\alpha)/(2\alpha\cos 2\alpha - \sin 2\alpha);$$

$$C = -b\sin 3\alpha/(\sin 4\alpha + 2\sin 2\alpha);$$

$$D = b\sin\alpha/\{3(2\sin 2\alpha + \sin 4\alpha)\};$$

$$E = c/\sin 2\alpha;$$

$$F = (a - 2\alpha c)/(2\alpha\cos 2\alpha - \sin 2\alpha);$$

$$G = b\cos 3\alpha/(2\sin 2\alpha - \sin 4\alpha);$$

$$H = -b\cos\alpha/\{3(2\sin 2\alpha - \sin 4\alpha)\}.$$

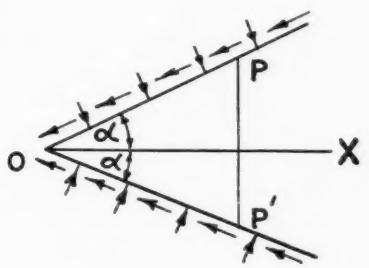

FIGURE 1.

In particular for the case $\alpha=45°$, when the wedge is right-angled:

$$\Omega(z)=-az+2icz\log z-\frac{b}{2\sqrt{2}}(1-i)z^2$$

$$\omega(z)=[c+i(a-\pi c/2)]z^2+\frac{b}{6\sqrt{2}}(1+i)z^3$$

so that $2\Theta=2(\overline{x}x+\overline{y}y)=\Omega'(z)+\overline{\Omega}'(\bar{z})$

$$=-2a-4c\tan^{-1}(y/x)-2\frac{b}{\sqrt{2}}(x+y)$$

and

$$-2\Phi=-2(\overline{x}x-\overline{y}y+2i\overline{x}y)=z\overline{\Omega}''(\bar{z})+\overline{\omega}''(\bar{z})$$

$$=-\frac{2ic}{x^2+y^2}(x^2-y^2+2xy)-\frac{b}{\sqrt{2}}(x-y+ix+iy)+$$

$$+2[c-i(a-\pi c/2)]+iy)+\frac{b}{\sqrt{2}}(x-y-ix-iy),$$

so that separating real and imaginary parts:

$$\overline{x}x=\frac{-cxy}{x^2+y^2}-c\tan^{-1}(y/x)-\tfrac{1}{2}(a+c)-\frac{b}{2\sqrt{2}}(x+y),$$

and so on.

LOADING ALONG BOTH EDGES OBEYING A GENERAL POLYNOMIAL LAW

This case though completely general is of theoretical rather than practical interest but is given as an alternative approach to the slightly less general solution of Timoshenko.

We now have:

$$\overline{nn}=-(a+b_1e^{-i\alpha}z+\ldots\ldots+b_ne^{-ni\alpha}z^n)\qquad\text{along}\quad\theta=\alpha$$

$$\overline{ns}=-c$$

$$\overline{nn}=-(p+s_1e^{+i\alpha}z+\ldots\ldots+s_ne^{+ni\alpha}z^n)\qquad\text{along}\quad\theta=-\alpha$$

$$\overline{ns}=-q$$

leading to the boundary conditions:

$$\Omega(z)+z\overline{\Omega}'(\bar{z})+\overline{\omega}'(\bar{z})=$$

$$-4\left[a+ic+\frac{b_1}{2}ze^{-i\alpha}+\ldots\ldots+\frac{b_n}{n+1}z^ne^{-ni\alpha}\right]z\qquad\text{along}\quad\theta=\alpha$$

and:

$$\Omega(z)+z\overline{\Omega}'(\bar{z})+\overline{\omega}'(\bar{z})=$$

$$-4\left[p+iq+\frac{s_1}{2}ze^{+i\alpha}+\ldots\ldots+\frac{s_n}{n+1}z^ne^{+ni\alpha}\right]z\qquad\text{along}\quad\theta=-\alpha$$

so that assuming complex potentials now of the form

$$\Omega(z)=Az+iBz\log z+\sum_2^{n+1}(C_r-iD_r)z^r$$

$$\omega(z)=\sum_2^{n+2}(E_r-iF_r)z^r \qquad (6)$$

the various constants being all real, we are led, after equating coefficients, to the results:—

$$A=-[(a+q)\sin 2\alpha+(c-q)\cos 2\alpha]/\sin 2\alpha;$$

$$B=2[(a-p)\cos 2\alpha-(c+q)\sin 2\alpha]/(2\alpha\cos 2\alpha-\sin 2\alpha);$$

$$C_2=\frac{-(b_1+s_1)\sin 3\alpha}{2\sin 2\alpha(1+\cos 2\alpha)};\qquad D_2=\frac{(b_1-s_1)\cos 3\alpha}{2\sin 2\alpha-\sin 4\alpha};$$

$$E_2=\frac{c-q}{\sin 2\alpha};\qquad F_2=\frac{(a-p)-2\alpha(c+q)}{2\alpha\cos 2\alpha-\sin 2\alpha};$$

$$E_3=\frac{(b_1+s_1)\sin\alpha}{3(2\sin 2\alpha+\sin 4\alpha)};\qquad F_3=\frac{-(b_1-s_1)\cos\alpha}{3(2\sin 2\alpha-\sin 4\alpha)};$$

$$C_r=\frac{-2(b_{r-1}+s_{r-1})\sin(2r-n+1)\alpha}{r(r\sin 2\alpha+\sin 2r\alpha)};$$

$$D_r=\frac{2(b_{r-1}-s_{r-1})\cos(2r-n+1)\alpha}{r(r\sin 2\alpha-\sin 2r\alpha)};$$

$$E_{r+1}=\frac{2(b_{r-1}+s_{r-1})[r\sin(2r-n-1)\alpha-\sin(n-1)\alpha]}{r(r+1)(r\sin 2\alpha+\sin 2r\alpha)};$$

and

$$F_{r+1}=\frac{-2(b_{r-1}-s_{r-1})[r\cos(2r-n-1)\alpha-\cos(n-1)\alpha]}{r(r+1)(r\sin 2\alpha-\sin 2r\alpha)}.$$

DECREASING POLYNOMIAL LOAD ALONG BOTH EDGES

Assuming:

$$\overline{nn}=-[b_0+b_1e^{i\alpha}z^{-1}+\ldots\ldots+b_ne^{ni\alpha}z^{-n}]\qquad\text{along}\quad\theta=\alpha$$

$$\overline{ns}=-c$$

and

$$\overline{nn}=-[p_0+p_1e^{-i\alpha}z^{-1}+\ldots\ldots+p_ne^{-ni\alpha}z^{-n}]\qquad\text{along}\quad\theta=-\alpha.$$

$$\overline{ns}=-q$$

[These forms of loading give infinities at the origin (apex of the wedge), but this can be avoided by later substituting $(z+a)$ for z. They also tend to a constant as z tends to infinity and fairly rapidly so.]

The boundary conditions are:—

$$\Omega(z)+z\overline{\Omega}'(\bar{z})+\overline{\omega}'(\bar{z})$$

$$=-4\left[b_0z+icz+b_1e^{i\alpha}\log z+b_2e^{2i\alpha}\frac{z^{-1}}{-1}+\right.$$

$$\left.+\ldots\ldots+b_ne^{ni\alpha}\frac{z^{-n+1}}{-n+1}\right]\qquad\text{along}\quad\theta=\alpha$$

$$=-4\left[p_0z+iqz+p_1e^{-i\alpha}\log z+p_2e^{-2i\alpha}\frac{z^{-1}}{-1}+\ldots\ldots+\right.$$

$$\left.+p_ne^{-ni\alpha}\frac{z^{-n+1}}{-n+1}\right]\qquad\text{along}\quad\theta=-\alpha.$$

We now assume potentials:

$$\Omega(z)=(X-iY)\bar{z}+(A-iB)z/\bar{z}+(R-iS)(z/\bar{z})\log z+$$

$$+\sum_1^{n-1}(C_r-iD_r)z^{-r}$$

and

$$\omega(z)=(P-iQ)\log z+(L-iM)z^2+(F-iH)z\log z+$$

$$+\sum_1^{n-1}(E_r-iG_r)z^{-r}$$

$$\ldots\ldots\ldots\qquad (7)$$

the various constants all being real as before. If we now

write down the boundary conditions and equate the various coefficients we find the constants to be given by:

$$R=-(p_1+b_1)/\cos\alpha; \qquad S=(p_1-b_1)/\sin\alpha;$$

$$L=2(c-q)/\sin 2\alpha; \qquad M=-2(c+q)/\cos 2\alpha;$$

$$X=(q-c)/\sin 2\alpha-(b_0+p_0)/\cos 2\alpha;$$

$$Y=(b_0-p_0)/\sin 2\alpha-(c+q)/\cos 2\alpha;$$

$$F=-4b_1\cos\alpha-(p_1-b_1)\sin 2\alpha/\sin\alpha+ \\ +(p_1+b_1)\cos 2\alpha/\cos\alpha;$$

$$H=-4b_1\sin\alpha+(p_1-b_1)\cos 2\alpha/\sin\alpha+ \\ +(p_1+b_1)\sin 2\alpha/\cos\alpha;$$

$$A=4b_1\cos\alpha+(p_1-b_1)\sin 2\alpha/\sin\alpha- \\ -(p_1+b_1)\cos 2\alpha/\cos\alpha+(p_1-b_1)/\cos\alpha\cos 2\alpha;$$

$$B=-4b_1\sin\alpha+(p_1-b_1)\cos 2\alpha/\sin\alpha+ \\ +(p_1+b_1)\sin 2\alpha/\cos\alpha+(p_1-b_1)/\sin\alpha\cos 2\alpha;$$

$$C_r=2(p_{r+1}+b_{r+1})\sin(r-1)\alpha/\{r(\sin 2r\alpha+r\sin 2\alpha)\};$$

$$D_r=2(p_{r+1}-b_{r+1})\cos(r-1)\alpha/\{r(\sin 2r\alpha-r\sin 2\alpha)\};$$

$$E_r=-2(2+r)(p_{r+2}+b_{r+2})\sin(r+2)\alpha/ \\ [(r+1)r\{\sin 2(r+1)\alpha+(r+1)\sin 2\alpha\}]$$

$$G_r=2(r+2)(b_{r+2}-p_{r+2})\cos(r+2)\alpha/ \\ [(r+1)r\{\sin 2(r+1)\alpha-(r+1)\sin 2\alpha\}].$$

However, from the coefficient of z^{-1}

$$(C_1-iD_1)-(C_1+iD_1)e^{4i\alpha}+(P+iQ)e^{2i\alpha}=4b_2e^{2i\alpha}$$

and

$$(C_1-iD_1)-(C_1+iD_1)e^{4i\alpha}+(P+iQ)e^{-2i\alpha}=4p_2e^{-2i\alpha}$$

which give:

$$(C_1-iD_1)2i\sin 2\alpha+(C_1+iD_1)2i\sin 2\alpha=4(p_2-b_2)$$

whence

$$C_1=0 \text{ and } 2D_1\sin 2\alpha-2D_1\sin 2\alpha=4(p_2-b_2),$$

and these equations are only consistent if $p_2=b_2$, in which case

$$C_1=D_1=0 \text{ and } P=b_2=p_2, \quad Q=0.$$

However, we can adjust our variables so that the coefficient of any one particular term in the polynomial expressions for the boundary loads is the same, so that this solution may be regarded as general. Alternatively, we can reduce the polynomial expressions so that the terms in question become zero, and we will consider this to have been done in the following example, which is that of the inverse square law.

In this case we can write:

$$\overline{nn}=-b_2e^{2i\alpha}z^{-2}, \qquad \overline{ns}=-c \qquad \text{along } \theta=\alpha$$

$$\overline{nn}=-p_2e^{-2i\alpha}z^{-2}, \qquad \overline{ns}=-q \qquad \text{along } \theta=-\alpha$$

the boundary conditions being:

$$\Omega(z)+z\Omega'(\bar z)+\overline{\omega}'(\bar z)=-4\left[icz+b_2e^{2i\alpha}\frac{z^{-1}}{-1}\right] \qquad \text{along } \theta=\alpha$$

and

$$=-4\left[iqz+p_2e^{-2i\alpha}\frac{z^{-1}}{-1}\right] \qquad \text{along } \theta=-\alpha.$$

These conditions may be satisfied by assuming:

$$\Omega(z)=(X-iY)\bar z+(C_1-iD_1)z^{-1}$$

$$\omega(z)=(L-iM)z^2,$$

from which we have:

$$L=(c-q)\sin 2\alpha; \qquad M=-(c+q)/\cos 2\alpha;$$

$$X=(q-c)/\sin 2\alpha; \qquad Y=-(c+q)/\cos 2\alpha;$$

$$C_1=-(b_2+p_2)/\cos 2\alpha; \quad D_1=(b_2-p_2)/\sin 2\alpha.$$

In the particular case in which there is such a normal loading along one edge only, we have:

$$\overline{nn}=-be^{2i\alpha}(z+a)^{-2}, \qquad \overline{ns}=0 \qquad \text{along } \theta=\alpha$$

$$\overline{nn}=\overline{ns}=0 \qquad \text{along } \theta=-\alpha$$

(writing $z+a$ for z so as to avoid an infinity at the origin).

Then:

$$\Omega(z)=[-b/(2\sin 2\alpha)-ib/(4\cos 2\alpha)](z+a)^{-1}$$

$$\omega(z)=0.$$

Now,

$$z\Omega''(\bar z)+\overline{\omega}''(\bar z)\equiv z\overline{\Omega}''(\bar z)=-2(\overline{xx}-\overline{yy}+2i\overline{xy}) \\ =-b[1/\sin 2\alpha-i/(2\cos 2\alpha)]z(\bar z+a)^{-3}$$

so that along the central line, $z=\bar z=r$ we get

$$-2(\overline{xx}-\overline{yy}+2i\overline{xy})=- \\ -b[1/\sin 2\alpha-i/(2\cos 2\alpha)]r(r+a)^{-3}$$

therefore,

$$\overline{xx}-\overline{yy}=br/[2\sin 2\alpha(r+a)^3]$$

and

$$2\overline{xy}=-br/[4\cos 2\alpha(r+a)^3].$$

The maximum shearing stress τ is thus given by:

$$4\tau^2=\frac{b^2r^2}{4(r+a)^6}\,\frac{1+3\cos^2 2\alpha}{\sin^2 4\alpha}$$

which is greatest for $\tan 2\alpha=-(4)^{1/3}$, and decreases rapidly with increasing r so that the infinite wedge can be suitably made to replace the finite wedge.

*Results of Photoelastic Investigation of Stresses in a Tension Bar with Unfilled Hole**

by

H. T. JESSOP, T.D., M.Sc., F.Inst.P., C. SNELL, M.Sc., and I. JONES, B.Sc.
(Col. Jessop and Mr. Snell are respectively Reader and Lecturer in Photoelasticity at University College, London; Mr. Jones is on the staff of Vickers-Armstrongs, Weybridge)

ALTHOUGH THIS PROBLEM is one which has been investigated by many photoelasticians, there appears to be no record of any systematic exploration of the effect upon the stress distribution of the ratio of hole-diameter to width of bar.

In this investigation tests were made upon a standard sized bar with four different sizes of holes, and the stress distribution on the cross section of the bar through the hole centre was explored for the four cases.

DETAILS OF TEST BARS

The bars were of width one inch and thickness $\frac{1}{8}$ in., and the hole sizes investigated were $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{3}{8}$ in. and $\frac{1}{2}$ in. diameter. The materials used were Araldite B for measurement of the stress differences and Perspex for tracing the directions of principal stress.

The holes in the bar were formed by a succession of small cuts with centre-pin cutters.

The models were sensibly free from initial and machining stresses, but a certain amount of time-edge stress developed due to absorption of moisture from the atmosphere, and this prevented the accurate direct measurement of boundary stresses.

The models were examined under load using monochromatic light in a projection polariscope with a magnification of five.

In making these tests, observations were confined to the section of the bar *AB* through the centre of the hole (*see* sketch on Fig. 1). The distribution of the principal stress-difference, $P-Q$, on this section was first obtained by plotting a graph of the fringes observed in the polariscope. In all cases reliable observations could be obtained to within about 0·01 in. of the boundary, and the peak values at the boundary were then obtained from the graphs by extrapolation. This procedure eliminated the effect of the time-edge stresses in the model but introduced a possible error in the value obtained for the peak stress, the magnitude of which was greatest in the case of the smallest hole, where the rate of change of stress near the boundary was itself changing rapidly.

The transverse stress Q at points on the section *AB* was obtained by the shear-slope integration method.

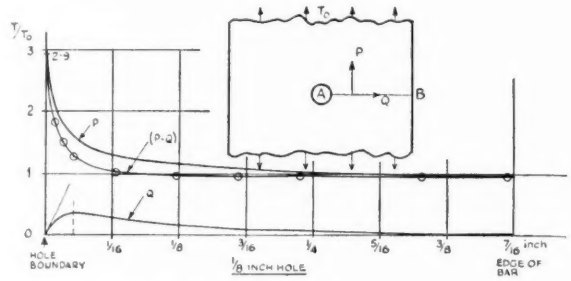

FIGURE 1.

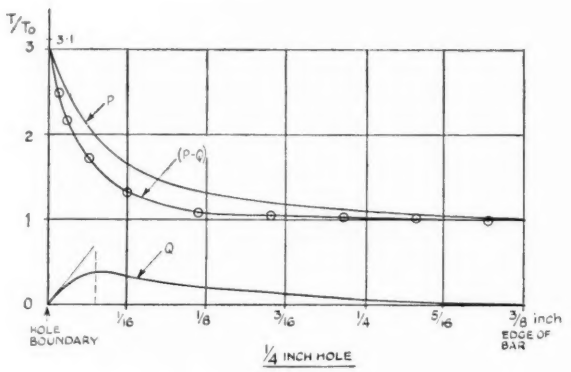

FIGURE 2.

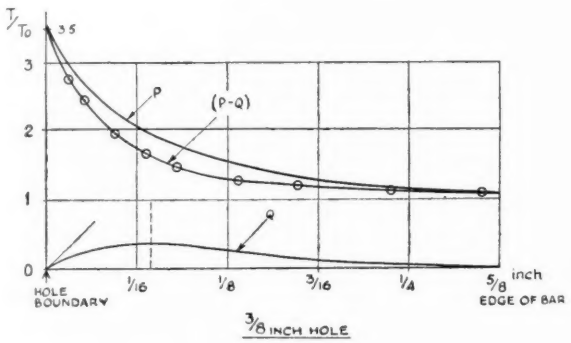

FIGURE 3.

*This investigation is part of the Royal Aeronautical Society's Photoelastic/Fatigue Programme in connection with the Strength of Bolted Joints. (*See* previous Technical Note in the June JOURNAL.)

Received October 1954.

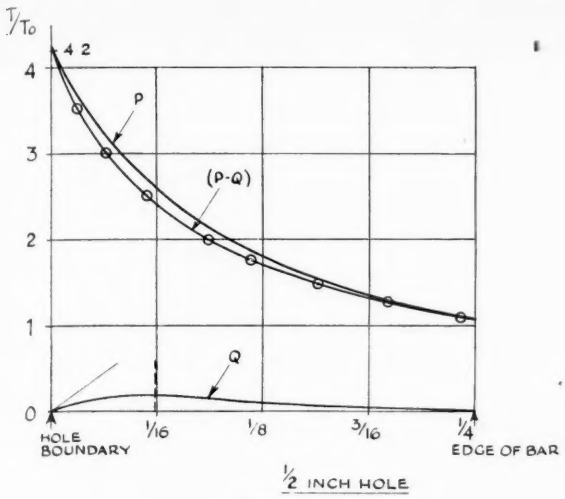

FIGURE 4.

The mean tension T_0 in the undrilled bar was obtained by measurement of the relative retardation in a region where the stress was uniform across the width of the bar.

Figures 1-4 show the distribution of the stress difference and of the separate stresses in the four cases.

Figure 5 shows the variation with hole diameter of the stress concentration factors for the peak stress on the hole boundary.

Figure 6 gives a comparison of the distribution of stress difference under loads which produce the same mean tension across the section of the bar through the hole centre.

The estimated accuracy of the results is:

(*a*) for the values of the stresses within the range of observations, ±2·5 per cent.;

(*b*) for the values of the peak stresses obtained by extrapolation, ±5 per cent.

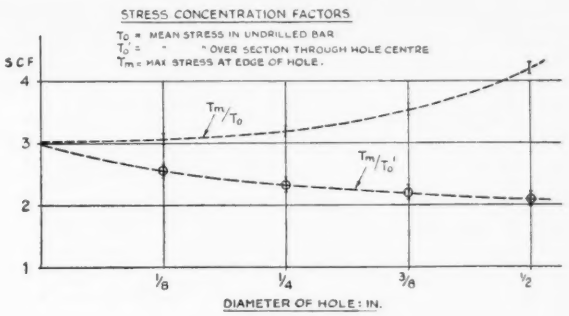

FIGURE 5.

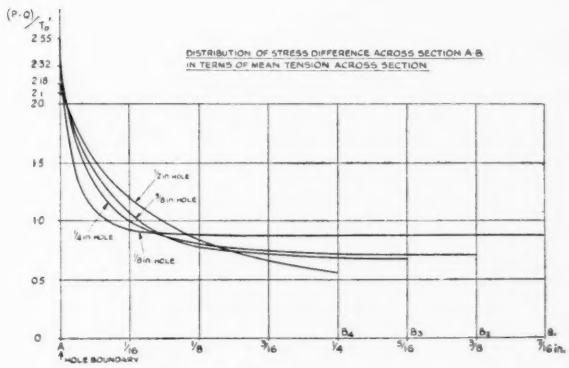

FIGURE 6.

ACKNOWLEDGMENTS

The authors wish to thank the staff of the Royal Aeronautical Society for their help in various ways.

THE LIBRARY

Reviews

THE PAPERS OF WILBUR AND ORVILLE WRIGHT.
Edited by Marvin W. McFarland. McGraw Hill, New York.
December 1953. *Two Volumes.* 1,278 *pp. Illustrated.* £10

(These two volumes are considered to be of such importance that they have been specially reviewed for the JOURNAL *from the Aerodynamics, Structures and Engine aspects, together with an appreciation of the Wright Brothers themselves, by former Wilbur Wright Memorial Lecturers.)*

The Wright Brothers

by

LT.-COL. A. OGILVIE, C.B.E., F.R.Ae.S.
(*Wilbur Wright Memorial Lecturer* 1922)

THE IMPORTANCE of the two volumes of "The Papers of Wilbur and Orville Wright" is very great to anyone interested in the beginning of the era of human flight, now affecting the lives of all peoples of the world.

The story of how this material came to be assembled and sorted out is shown very clearly in the Introduction, and great credit is due to the Editor, Mr. McFarland and his Staff, for the excellent way in which it has been done and for the way in which it has been presented. As much again still remains in the Library of Congress, unpublished in these volumes, and in addition to that there is a quantity of letters which the Wrights wrote to friends outside the U.S.A.

From the point of view of the scientific student however, most of the material is included, and it must have been a formidable task to pick out what was to be put in and what left out.

The great majority of these Wright letters is by the hand of Wilbur and clearly shows the quality of his character and intellect.

Two books, Kelly's "The Wright Brothers" and his "Miracle at Kitty Hawk" should be read as well as these two Volumes of Papers, if the reader wishes to get a clearer picture particularly of the European negotiations of 1906 and 1907 and of the characters of the two brothers. It should be kept in mind however that Kelly did not meet Orville till 1914. He never met Wilbur.

As Wilbur wrote of himself to his father "intellectual effort is a pleasure to me," whereas Orville's delight was in flying and experimental work, although when he was forced to it, he could express himself as clearly and as simply as Wilbur. I remember when I was trying, in 1909, to teach myself to make a turn on a glider but could not get the hang of it, a letter came from Orville which explained how to do it so simply that it came to me right away. After Wilbur's death, Orville had to do the writing and his letters were very clear and instructive.

A great deal of these papers, perhaps too much, is devoted to correspondence between Wilbur and Octave Chanute, which began in May 1900, and continued till Chanute's death in 1910. In 1900 Chanute was 68 and had a national reputation as a civil engineer, and an international one as the author of "Progress in Flying Machines" published in 1894, and which assembled all available information up to that time. He was the centre of a large correspondence with experimenters all over the world, and had had a glider built of Lilienthal type, and others of his own design, with which his young assistants had made many short glides. At this date, 1900, Wilbur was 33 with no training or experience as an engineer except what he and his brother had taught themselves in their bicycle shop. Yet these disparities did not appear in their letters. Chanute never tried to impose himself, nor Wilbur to humble himself.

Right at the beginning, in 1900, Chanute gave some sound advice about methods of experimentation, and in the next year gave encouragement at a critical moment. Relations between the Wrights and Chanute remained very cordial for many years, and became clouded only towards the end. Wilbur's letters to Chanute early in 1910, referring to these matters, show how much he was upset, and anxious to clear the misunderstandings. They are typical of his fine character as well as of his ability to express himself with the greatest clarity.

A careful study of this Wright-Chanute correspondence leaves me with the impression that Chanute never really understood how the Wright aeroplane was controlled. In a letter of his, dated January 19th 1908, he expresses belief that the Wrights overcame centrifugal force on a turn "by shifting the weight," a manifest absurdity.

When the work of the Wrights themselves is considered, as revealed in these "Papers," it is impossible to avoid a feeling of awe that such a straight course was made through so many obscurities. Very little real help was obtained from anything which had been done, or written, before the quest began, except that to learn how to control an aeroplane was the first step. Their own initial ideas were that safety in the methods of experiment, a strong structure and the greatest caution were essentials, and that it was probably better for the pilot to use his brains and his muscles to alter the angles of incidence of the wings for lateral balance, rather than to use his weight. This last idea turned out to be correct and of absolutely basic importance. It is still in use on every aeroplane today.

The idea of placing the small horizontal surface in front of the main planes, with the front part of the surface fixed, and the rear part movable, and under *the eye* and control of the pilot, was worked out by consideration of their scanty knowledge about the travel of the centre of pressure.

After short spells of gliding and testing in horizontal and rising winds at Kitty Hawk in 1900 and 1901, the two brothers were satisfied that they had the right ideas about control, although they were aware that there was still something missing, but they also saw that all the data on which they based the size, sections, and shape of their

wings, were so inaccurate as to be useless in developing a flying machine, which has to be efficient before it can fly at all.

This was the moment of discouragement when Chanute was of real help by assuring them that they were far in advance of anyone. He had been in camp with them for a week in 1901.

Within a few weeks of their return to Dayton, the Wrights had begun experimenting with a wind tunnel, and towards the end of November were making a series of small model surfaces to test in it. By December 7th the series of lift measurements were complete. In a letter Wilbur wrote, "We can make a complete chart of the lifts of a surface from 0° to 45° in about an hour!" and he thought the experimental error to be less than 5 per cent.

After finishing their "vacation" at this point, the two brothers had to go back to their regular bicycle business. When they returned to Kitty Hawk at the end of August 1902, they had re-designed their glider, making the wings of the same area, but of much wider span and less chord, in accordance with the wind tunnel results. They also fitted a fixed vertical fin at the rear, in order to counteract the tendency of the wing, with the bigger angle and bigger resistance to lag behind.

The new glider was very much more efficient than last year's, but a new trouble now appeared. When the wings had a lateral tilt, and the glider began to sideslip, the wind pressure on the lower side of the fin tended to turn the course of the glider into a spiral, and the lower wing got lower till it touched the sand. Some very good glides were made, but this serious fault in the control system persisted until Orville suggested that the fin should be made into a rudder, which would enable the pressure to be applied on the upper side, in the situation as above. The glider could thus be kept on its course, either when going straight, or on a turn. Wilbur immediately suggested that the wing warp and rudder should be interconnected, and the thing was done. A controllable aeroplane was in their hands.

When the Wrights left Kitty Hawk at the end of October 1902, they were confident they could make an aeroplane which would carry a motor and fly safely. They did, in fact, propose to build an aeroplane big enough for this, and try it out first as a glider, and then put in the motor, but when it came to the point this programme was never carried out. From now on their whole time and energies were devoted to designing this aeroplane and to building motor, propellers, and a transmission system. The design of the propellers gave them a lot of trouble, but the motor, not very much, and by the end of September 1903 they were back at Kitty Hawk gliding, or building the power machine, or a larger shed, whichever the weather allowed to be best. They were certain of success, and their letters and notebooks show no trace of uneasiness.

On December 17th 1903, four flights were made, the best one lasting 57 seconds against a wind of 24 m.p.h. The engine developed about 12 h.p.

During 1904 and 1905 they were practising in a 70-acre field near their home in Dayton. The field was very rough and lumpy, and they had to develop a method of assisting the start with a derrick and falling weights. Complete circles were accomplished towards the end of 1904 and flights up to five minutes' duration, but there was still unexplained trouble with the controls.

In 1905 the control trouble was discovered to be due to stalling on a turn, and flights up to 38 minutes were made. Their engine was now giving 18 to 20 h.p.

There were, of course, innumerable minor troubles and minor accidents during these five years of experiment, and it is to be hoped that this brief summary will induce all interested in aeronautics to read the extremely interesting story in full.

For the next two years there were tedious and unsuccessful negotiations with the French, British and German Governments, as well as with the American. If a reader does go through this story in detail, he should keep in mind that there was at that time a great and increasing military tension in Europe, particularly between France and Germany, with Russia and England on the side lines; also that there was a belief in France that a Frenchman must be the first to fly, simply because they were the first to develop the balloon and the motor car and the lightweight petrol engine, and that they might expect at any moment to light on some wonderful secret which would give them the mastery of the air. The firmness of this belief waxed and waned according to the latest aeronautical news.

There were also some highly dubious manoeuvres among the politicians and the newspapermen. Wilbur and Orville established perfect confidence in their own integrity and business abilities with all whom they met, but some of the newspaper men, and some of the would-be flying men maintained that all the stories about the flights in America were bluff. In Germany the difficulties centred round the nervousness of the officials, lest there should be any mistake which would expose them to the criticism of the almighty Kaiser.

There is one thing which the publication of these Papers should do and that is to obliterate the myth about the secretiveness of the Wright brothers. This myth should really be attributed to the Press in the United States, where the Press and the general public had no belief in the possibilities of human flight.

The failure of the full-sized Langley machine after the expenditure of considerable sums of public money confirmed this belief. In England there was nothing like so much scepticism. The Wrights went to Kitty Hawk for their gliding and initial flights because it was a suitable place to experiment and not because it was inaccessible to the public.

Their field at Simms, eight miles from the large town of Dayton was alongside a main road and a railway with frequent electric cars. Nothing could have been more public.

The Wrights had expended a great deal of their resources and had inevitably taken a lot of risks in their experiments and very properly hoped to make some money so that they could go on with their research work. They had a master patent and did in the end win every patent action, but they knew very well how difficult it would be to prevent infringements and it was for that reason that they wished to sell their machine, their patents and all their acquired knowledge, to a Government, preferably their own.

In January 1908 the Wrights made an offer to the U.S. Signal Corps which was accepted in February, and next month a contract was also signed with a new French Syndicate.

With these two major jobs on their hands the two brothers went to Kitty Hawk to practise with a two-seater machine which Orville had worked out, and in which the pilot sat upright and operated the lateral controls with his right hand instead of with his body as had been done up to that time. The horizontal position was too tiring to the neck.

After this, Wilbur made for Paris to fulfil the French contract and Orville to get ready for the American one.

It was more than two months before Wilbur made the first flight in Europe, but when he did, there was tremendous excitement, with spectators bursting into tears. I found myself doing that when I first saw a man doing what had always been considered an impossibility. The French flying people saw that they were completely outclassed, and admitted it freely.

A month afterwards Orville was making sensational flights of over an hour at Fort Myers for the United States contract, but after about a fortnight there was a disastrous accident, the passenger, Lieut. Selfridge, being killed and Orville breaking his thigh.

So Wilbur took up the running and began making lengthy flights. The great strain under which he was working at this period is clearly shown by his haggard appearance in Plate 166.

At Pau, where Orville and his sister Katharine joined him, he was looking much better. There can be no doubt that the two brothers were much more contented and serene when they were together. Many instances of this can be picked out of these Volumes of Papers. But on the other hand, I have heard them in their Hawthorn Street home, arguing about some technical point and at first used to be quite startled at the fierce way they went at it. Any subject was pretty well chewed to bits before it was abandoned.

In October 1911 Orville took a party, of which I was one, to Kitty Hawk for some soaring experiments.

The footnote on page 1,025 says that one of the purposes of this trip was to test the automatic stabiliser, on which Orville had been working for a number of years.

In my belief, this was not the case, as there is no hint of it in Orville's own diary, nor in mine, which were both written at the time and on the spot. The matter is not, however, important.

When Wilbur died of typhoid, worn down at the age of 45 by his exertions over the patent actions, his father, Bishop Wright, recorded that " in memory or intellect, there was none like him." I think that all who knew him would agree.

He had a remarkable personality, great moral courage and tenacity of purpose.

No better instance of these characteristics could be found than his behaviour during his early flights in France, when he firmly refused to take any unnecessary risk, whatever the importance of the personalities who had come half across France to see him fly.

His politeness and modesty impressed all, great or humble. These were the very things which struck me when I first met him at the Dauphin Hotel, Le Mans, as a young, very unimportant person, meeting a man whose name was the talk of Europe. In a short talk he showed other qualities, humour and helpfulness, advising against a proposed method of learning to fly as too dangerous.

Later on, when he came over from Berlin to Eastchurch to help us to prepare my Baby Wright for the Gordon Bennett Race, and after a crash to repair it, he displayed mechanical abilities and a knowledge of materials which astonished us all. When work was done, he would delight us all with his reminiscences which were always given as comical a twist as possible.

We all felt that he was a great man, a man apart.

Orville was certainly not such a striking personality, but he was very remarkable for his inventive abilities and love of experiment, which lasted to the end of his 77 years of life. His principal object was to make flying safer, and he wrote many letters and articles with this in view.

Though perhaps not quite so careful in his preparation as Wilbur, he loved the actual flying more, and took some very big chances when he wanted to test something. He was shy, and refused to speak in public, but in private he was very charming and friendly.

He was always very neat and tidy, which Wilbur sometimes was not. Like Wilbur he was a first rate mechanic and knew exactly what to do and how to do it.

My last visit to the Wrights was in 1913, but I was kept in touch with the family by Griffith Brewer, who visited him nearly every year and remained one of his most faithful friends.

Aerodynamic Work

by

ERNEST F. RELF, C.B.E., F.R.Ae.S.
(*Wilbur Wright Memorial Lecturer* 1946)

In assessing the approach of the Wright Brothers to aerodynamic problems it must be remembered that they were not in any sense scientists, but practical engineers of great perception who owed most of their training to their own cycle business. Their approach to the subject is singularly like the pattern of aerodynamic research which has been followed since, even to the present day, consisting, as it did, of a blend of full scale and model experimentation, and a continual attempt to harmonise the two.

With the Wrights, the full scale work came first. From the beginning they realised the great importance of giving numerical precision to their observations, and in their earliest tests, before they had even taken a man into the air, they flew their gliders as kites and by measuring the tension in the restraining cables, the wind speed and direction, and the angle of incidence of the wings, they were able to get a clear idea of the forces acting on the glider. When they reached the stage of carrying a man they supplemented these measurements by observations in free flight. By gliding quite close to the ground down the slope of a sand-hill they knew that the direction of the wind must be very nearly parallel to the surface and from measurements of speed and angle of incidence they could again obtain the aerodynamic forces. The first kite measurements date from 1899 and the first free gliding tests from 1900. Their analysis of the results of these tests shows that they were quite sound in their knowledge of elementary applied mechanics and understood how to resolve the velocities and force components, though they expressed these in a form rather different from that now used. As early as 1901 they had carried out experiments on the relative merits of flat and curved surfaces and come to the conclusion that the latter were the more

efficient. They then recorded a maximum lift-drag ratio of 8·4 on a glide. Incidentally they made a sighting clinometer for measuring the angle of the wing chord to the horizontal from the ground. For wind speed measurements they relied on vane anemometers, either on the ground or carried in the machine, and they had many doubts about the accuracy of these instruments but no means of making a proper calibration.

As a result of all this work the Wrights came to have considerable doubts about the accuracy of Lilienthal's tables, which seem to have been their only source of external information at that time. It was this doubt that led them to explore the possibilities of model tests. Their first effort was to mount an aerofoil and a plate normal to the wind on the rim of a bicycle wheel with its axis vertical. This device was propelled through the air by mounting it in front of a ridden bicycle, and an attempt made to balance the lift on the aerofoil against the drag of the normal plate. They did not find this method satisfactory, but it is an interesting example of their ingenuity. Their wind tunnel was built in 1901 and had a cross-section 16 inches square, with a wind speed of about 50 feet per second. They used straighteners and a honeycomb to secure uniform air flow and drove the tunnel by a fan coupled to a gas engine. In this tunnel they tested a great variety of aerofoils of different thickness, camber and aspect ratio and were soon in the possession of information which enabled them to discuss the design of their gliders and aeroplanes in a much more realistic light.

The satisfaction felt in the use of this apparatus is well illustrated by a remark of Chanute, who exclaimed, "It is perfectly marvellous to me how quickly you get results with your testing machine . . . you are evidently better equipped to test the endless variety of curved surfaces than anybody has ever been."

The Wright Brothers seem never to have weighed the forces on their models directly; they devised their balances so that the lift, or drag, was balanced against the drag of a rectangular plate of suitable size normal to the wind. They had a great deal of argument as to the correct coefficient to use for this normal force and finally decided upon $0{\cdot}0033\ V^2$ pounds per square foot, with V in miles per hour, equivalent to a drag coefficient of 1·3 in modern terms. The Wrights used normal plates of various shapes, sometimes nearly square and sometimes with an aspect ratio of five or 20, and did not seem to be aware that the normal force coefficient was a function of the aspect ratio. Nevertheless they seem to have been extremely well satisfied with the results of their model experiments. Of course, they got accurate comparative results even if their absolute values were not all that they might have been. They claimed, however, very good agreement with flight tests and considered that they had established a sound basis for the design of their powered aeroplanes, indeed they seem to have used these early wind tunnel data for all their subsequent designs. It could be expected that the lift slope would not be greatly in error, even at the very low Reynolds number (less than 10^5) of the Wright tunnel, and the drags may well have been accidentally closer than would be expected. The models used were very well made, usually of metal, so that at the low Reynolds number it is quite possible that there was a substantial region of laminar flow in the boundary layer, and that the resulting low drag offset the scale effect from model to full size glider. Be this as it may, the Wrights discovered, from their wind tunnel work, quite a number of facts about aerofoil performance which were rediscovered by later workers with much more elaborate apparatus. They were quite familiar with the effects of aspect ratio, with the travel of centre of pressure on aerofoils of different thickness and camber, with the decreased efficiency of a biplane as compared with a monoplane, and with the importance of streamlining struts and other parts of the structure. They were also aware that maximum lift-drag ratio occurred when "drift" and "head-resistance" were the same, or as we should now say, when the induced and profile drags were equal, though they did not seem to have connected this fact with an induced drag varying as the square of the lift. They do not seem to have thought of the possibility of making pressure distribution measurements on surfaces in order to determine the loading on their structures, but, in passing, it is interesting to note that they made strength tests on actual wings by inverting them on trestles and loading them with sand-bags.

This brief account, and, still more, a study of the published letters of the Wright Brothers, shows how very comprehensive and painstaking were their attempts to understand the aerodynamics of performance. When it comes to stability and control they seem never to have attempted any precise measurements, except those relating to centre of pressure travel on aerofoils, though they were quite familiar with the important problems involved. It was very early in their work that they realised the primary importance of rolling control and devised their wing warping method for producing large rolling moments. This device is first described in 1899 and was applied to a kite, the control being actuated by means of the cables used to tether the machine. The Wrights were very satisfied with this control and kept the idea a particularly close secret. They say, again and again, that they considered the problems of stability and control to be more difficult and more important than those of mere performance in the design of a successful flying machine. In applying their knowledge, first to their gliders and later to the powered machines, they showed the utmost wisdom by refusing, despite the obvious temptation, to fly more than a few feet above the ground until they felt that they had thoroughly mastered the problem of control. It was this great care in flying, coupled with their invention of a far better lateral control than anyone else had envisaged, which contributed most to their freedom from serious accidents and to their early success with a powered machine: the first powered flight of December 17th 1903 came only about four years after the Wright's first serious interest in the problem.

With regard to the design of propellers, there is not so much detailed information in the letters as there is concerning the aeroplane itself. The Wrights were obviously working on the propeller problem all the time, but there are few references to their thoughts on this subject, and the main clue to their reasoning comes from the note books they left. From these it is clear that they largely thought out the problem for themselves though they seem to have been familiar with the work of Froude on marine screw-propellers. Chanute drew their attention in the summer of 1903 to the work of Drzewiecki on strip theory as applied to airscrew blades. Wilbur, referring to this, says, "The author's methods of thought and expression are so different from my own that it has been no easy matter to master his paper." The method used by the Wrights was, in effect, the calculation of thrust and torque due to a single blade element situated at what they called the centre of pressure of the blade, and using finite aspect ratio data derived from wind tunnel tests. It was thus much like the simplified 0·7 radius method used in later times. The

Wrights correctly analysed the resultant velocity at the blade section due to rotational and forward components of the motion, and by resolving the appropriate aerodynamic reactions on the element found the thrust and torque. They do not seem to have thought of doing this at various blade radii and integrating to get the overall effect. However, they obtained results which were sufficiently accurate for their purpose and which led to propeller designs that gave quite a close approximation to the desired thrust. They tested their propellers under static conditions, but of course could not measure thrust in flight.

In summarising the aerodynamic work of the Wright Brothers it seems quite clear that they were the first to appreciate clearly the problems involved both in regard to performance and to stability and control, and to set out to solve these problems by careful experimentation with kites and gliders and with models in an artificial wind. The way in which they proceeded gradually to build up the knowledge they required, and to check in every possible way the accuracy of the results they obtained, is an example which can take its place in the highest tradition of original research. Considering the primitive methods and apparatus at their disposal and their lack of any deep theoretical training, it is almost incredible that they could have done so much in so short a time.

From the Structural Standpoint

by

N. J. HOFF, F.R.Ae.S.

(*Wilbur Wright Memorial Lecturer* 1953)

The most interesting observation any structures man reading "The Papers of Wilbur and Orville Wright" is bound to make, is the absence of worries on the part of the Wrights regarding the strength of their gliders and motor-driven aeroplanes. Their attention was directed toward problems of the power requirements of flight, and even more toward the stability and manoeuvrability of aeroplanes. This is understandable if one remembers that applied aerodynamics was a non-existent science in 1900 while the theory of structures had been developed to a most practical tool in the hands of civil engineers. The famous textbook "The Theory and Practice of Modern Framed Structures" by Johnson, Bryan, and Turneaure was published in New York in 1893.

But this fact alone does not explain the confidence of the Wright Brothers in the structural integrity of their machines. They had, to a very unusual degree, the ability of the rural American to use his hands and brain in erecting buildings and tinkering with machinery. They considered this knowledge so obvious and uninteresting that the construction of a hangar in Kitty Hawk with two end walls opening up completely is mentioned in Orville Wright's diary of 1903 only in terse sentences as in the following quotation: "Worked on building. Have sides on and lathing on roof. Put on part of the paper. Very little wind."

They built the machines they flew with their own hands and they maintained them with the utmost care. After Orville's bad accident at Fort Myer in 1908 Wilbur wrote to his sister Katharine: "I cannot help thinking over and over again, 'If I had been there, it would not have happened' . . . I do not mean that Orville was incompetent to do the work itself, but I realised that he would be surrounded with thousands of people who . . . would consume his time, exhaust his strength, and keep him from having proper rest . . . I cannot help suspecting that Orville told the Charleys to put on the big screws instead of doing it himself, and that if he had done it himself he would have noticed the thing that made the trouble, whatever it may have been. . . . Hired men pay no attention to anything but the particular thing they are told to do, and are blind to everything else."

This does not mean that structural engineers should not read "The Papers of Wilbur and Orville Wright." The story of the Wright Brothers is of great interest to every educated person. In addition, the development of early aeroplane structures can be followed in the many photographs of the book. They include Lilienthal's single-surface glider of 1894 and two-surface glider of 1895; Maxim's four-ton flying machine of 1894; Chanute's two-surface and multiple-wing gliders of 1896; Ader's "Avion" of 1897; Chanute's oscillating-wing glider of 1902; Langley's full-size machine of 1903; Ferber's Wright-type machine of 1903; Santos-Dumont's aeroplane of 1906; Farman's machine of 1908; and over a hundred pictures of various gliders and motor-driven aeroplanes built by the Wright Brothers. The Appendix of Volume II contains descriptions of all the Wright aeroplanes and three-view drawings of eleven of them.

Some of the ideas of the Wrights on structures can be seen from the following quotations:

"In answer to your inquiry as to whether there was any stress analysis of the original Wright airplane, and whether early aircraft constructors attempted strength calculations, will say that there was a stress analysis made of our first power machine as well as of the gliders which preceded it. These analyses, however, were not so complete as those made today.

"I suspect that stress analyses were made of Chanute's gliders, as Mr. Chanute was an engineer and bridge builder of high standing. As to the other early constructors I have no information." (Orville Wright to Willard A. Driggers on December 15th 1934.)

"The machine was a double-decker with surfaces 17 ft. by 5 ft. . . . The covering of the machine was French sateen, and it was put on bias so that no wire stays were needed to brace the surfaces diagonally. The uprights were jointed to the surfaces with flexible hinges and the whole machine trussed the long way, that is laterally, but not in the fore-and-aft direction. We used fifteen-gage spring steel wire. By tightening the wire *a*, every other wire was tightened. The surfaces were thus left capable of torsion, and this was the method we used to maintain lateral equilibrium." (Wilbur Wright to Octave Chanute on November 16th 1900.)

"We next began the designing of ribs, spars, etc., for our next machine, on which we had decided to put a motor with propellers. We had already before leaving Kitty Hawk about decided on many of the points of construction, but it takes considerable figuring to determine the proper sizes of the different parts so as to maintain a high enough

factor of safety in so large a machine." (Orville Wright to George A. Spratt on June 7th 1903.)

"Referring to paragraph No. 1, if the machines are supported by trestles at the last uprights of the wings, our Model C will stand a test far in excess of the load that is required of it in flight. We have tested this machine with a total load, including weight of machine of 1,960 pounds, without any sign of the spars or uprights bowing. . . .

"In order to give a test of a machine under conditions approximately those of the machine in flight, the machine should be supported upside down on trestles at the center and loaded with sand of uniform weight from tip to tip. The sand should be distributed fore and aft on the surfaces so that its center of gravity would come at the point of the center of pressure at different rates of speed at which the machine would be expected to fly." (Orville Wright to Lieutenant Henry H. Arnold on January 30th 1913.)

"However, I cannot quite agree with your reasoning as to the relative strength of large and small machines. The structure of a flying machine upon which its strength depends is that of a bridge. The greater portion of the total weight of the machine itself, as well as all of the load carried, is usually located approximately centrally between the two wing tips. I explained to Mr. Hendrick that, if the weight of the motive power and of the load to be carried could be equally distributed over the entire surface of the machine, there would be no limit to the size a machine could be built and still be strong enough to support its own weight in the air. But unfortunately such a machine would have no strength in landing with any type of landing gear at the present time." (Orville Wright to Charles A. Moran on May 11th 1917.)*

These excerpts from the Wright Papers indicate that the brothers had no doubts about their ability to design a structure safely when the loads were known. They did not worry much even about the loads; a safety factor applied to forces maintaining static equilibrium with the weight seemed to them a satisfactory solution of the problem. To the Wrights the only real difficulty that had to be overcome before man could fly was the stability and the control of the aeroplane.

It is of interest to remember how the importance of the various branches of the aeronautical sciences has kept changing in the past fifty or sixty years. By the twenties the early problems of balancing the aeroplane had been solved. Similarly, sufficient aerodynamic data had become available to make the performance calculations a routine procedure. The good designer was the engineer who knew enough about structures to make his aeroplane lighter than those of his competitors. The importance of structural design became even greater around 1930 when the thin-walled monocoque was generally adopted. But in the thirties monocoque structural design became a routine and in the forties the field of rapid progress shifted to aerodynamics and propulsion with the realisation of the jet engine and subsequently, of supersonic flight. Today, materials and structures again begin to move into the forefront of interest because they are likely to prevent high supersonic flight until the problems of aerodynamic heating are solved.

None of these problems could have been foreseen by Wilbur and Orville Wright when on December 17th 1903 they wired from Kitty Hawk to their father in Dayton: "Success four flights Thursday morning all against twenty-one mile wind started from level with engine power alone average speed through air thirty-one miles longest 57 seconds inform press home Christmas." The systematic work that preceded the first controlled powered flight of man in a heavier-than-air machine is told by the Wrights and by their friends in letters and diary entries in an unforgettable manner in the two volumes edited by Marvin W. McFarland. The short biographies of the aeronautical pioneers presented in the footnotes, their pictures, and the many photographs of contemporaneous aeroplanes, occasionally broken on the ground but more often victoriously flying in the air, virtually revive an exciting era in the history of mankind. No one interested in aeronautics should fail to read this book.

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*In his Wilbur Wright Memorial Paper, delivered on 14th September 1953 (January 1954 JOURNAL), Professor Hoff quoted from a letter written by Orville Wright to T. R. C. Wilson. This letter is not given in the two volumes under review, but is of such significance that it is reprinted here as a footnote, together with Professor Hoff's comments and quotation from a letter from Wilbur Wright to his father, and the entry in Orville Wright's diary for 16th November 1900, both of which appear in these volumes.—ED.

"The Wrights were most careful in selecting and testing the materials of construction and considered dynamic tests as important as static tests. On 6th September 1917 Orville Wright wrote to Thomas R. C. Wilson:

'In 1901, 1902, and 1903 we made a number of tests upon Eastern spruce and white pine. The spruces when kiln dried by the processes of that day were very inferior to the air-dried. The white pine did not seem to suffer so much in the dry kiln. The shock tests indicated that the spruce was superior to clear white pine. But the superiority of the spruce was more apparent in practical use in the machines.'

"The shock test is described in a letter Orville Wright wrote to F. O. Clements on 17th July 1917:

'I am giving below the results of the tests made on the several pieces of lumber which you sent me.

'The pieces tested were 1¼ in. square. A blow with a 21½ lb. wooden hammer was applied midway between the supports which were 20 in. apart.'

"On 23rd September 1900 Wilbur Wright tried to convince his father, the Reverend Milton Wright, that he was taking the necessary precautions to ensure that their glider was safe structurally:

'I am constructing my machine to sustain about five times my weight (700 lb. plus?) and am testing every piece.'

"Regarding the strength tests of the complete aeroplane one may refer to an entry in Orville Wright's diary made on 16th November 1903:

'We hung the machine on tips to test strength. The cloth wrinkled badly, necessitating a change in the trussing of the tips so that the strain be more evenly carried by front and rear spars and uprights. This requires a change in the controlling wires which will have to be operated at the rear. The uprights stood test of twice what will be required of them even though the wire connecting their centers had not been put in yet.'

"An entry on 17th November 1903, reads:

'Worked today on changing wires and in putting on wire to connect centers of front uprights. Supported at tips machine stood test of 440 lbs. at center without any signs of being overburdened.'"

How the Propulsion Problems were Tackled

by

SIR ROY FEDDEN, M.B.E., Hon.F.R.Ae.S.

(*Wilbur Wright Memorial Lecturer* 1944)

To all interested in the classic experiments which led up to the initiation of mechanical flight—and who is there in aviation who is not—the two volumes of the Papers of Wilbur and Orville Wright are of profound importance, and the collecting together of this information and deciding what to include and what to leave out must, indeed, have been a difficult task.

From the point of view of the student of propulsion, it is unfortunate that these volumes contain so little information about how the Wright engines were designed and developed, although a good deal more attention has been devoted to propeller problems. It would appear that Orville Wright was mostly concerned with engine work, and references are made to such items as his redesign of a connecting rod, attention to a faulty casting, but the information on engines generally is disjointed, and to complete this review reference has been made to other authorities.

It is worth noting that in spite of the fact that a patent for an internal combustion engine was taken out in England, about a hundred years earlier, and a large number of engines of a similar type were manufactured in France and run successfully about the middle of the Nineteenth Century, it would appear that almost all of the aviation pioneers, who were thinking round aeronautical power plant about the same time as the Wrights, with the single exception of Langley, concentrated on impractical steam and gun-powder prime movers, and thereby achieved nothing practical.

The fundamentals of the aeronautical propulsion formula, which the Wrights chose, go back to the constant volume Otto cycle and the momentum theory of Froude, both of which were established many years before they constructed their first internal combustion petrol engine, with its two chain-driven propellers. It was their skilful coalescence of the internal combustion engine, the propeller, and the fuel—all of which existed in other fields prior to 1903—which, combined together, made a sufficiently light, compact, and efficient propulsion system to enable mechanical flight to be realised.

Assuming it was in the year 1896 that the Wright Brothers first became actively interested in solving the problem of flight by studying the reports of Lilienthal's gliding experiments in Germany, it is nothing short of stupendous that in the short period of seven years they should have been able, while still carrying on their cycle business, to solve not only the practical flying and control problems by means of gliders, but also to undertake the construction of the airframe, the engine, and the propellers. The fact that they were able to produce a suitable power plant in this extraordinarily short time shows the measure and character of the men, their outstanding engineering ability and balanced thinking. They were calm, considered development engineers, in the true sense of the word; men of integrity and single purpose; just the type for the job. They did not belittle the difficulties, and having absorbed all aspects of the problem, they never swerved from their convictions; they faced them frankly, step by step, with courage and enthusiasm and with an inner appreciation that they knew what the pitfalls were and that if they did not cut corners they had every prospect of realising their ultimate goal.

The following excerpts from the Papers are typical of their approach:—

> When speaking of a motor: "It is with me a case of seeing before believing."
>
> When speaking of their own motor: "It furnishes in foot/pounds at the brake, energy equivalent to 23 per cent. of the heat units contained in the fuel."
>
> "It is not the power of the motor that counts but the amount of its power that is converted into useful work."
>
> "The thrust must be adapted to the speed at which the machine flies."
>
> "Our motor and machinery possess no extraordinary qualities; the best dividends on the labour invested have invariably come from seeking more knowledge than more power."
>
> "Our engine has been very satisfactory so far as reliability and strength are concerned, but its weight is many times greater than the French motors of the same horsepower rating. We think it is reasonably efficient, consuming less than 1 lb. of gasoline an hour per horsepower."

Whereas the problem of a suitable power plant must obviously have been continually in their minds for some years, they had to act quickly at the end of 1902 after their series of successful gliding experiments, and they knew they were ready for an engine. As soon as their calculations decided broadly the type and size of engine they wanted, they endeavoured to get somebody in America interested, but in this they failed, although by this time the Detroit area was making big strides in the manufacture of automobiles. Nothing daunted, however, the Wright Brothers set out to design their own engine. They engaged a skilled automobile mechanic, who, from their drawings, achieved the remarkable result of producing a suitable 4-cylinder engine in under two months. This was running fairly regularly on the test bench by the Spring of 1903.

There has always been some uncertainty as to the different types of engines the Wrights produced, and with the object of endeavouring to elucidate this matter, the following table has been built up from information gleaned from the two volumes of the Wright Brothers' papers and elsewhere. The absolute accuracy of every figure cannot be guaranteed. They are the best averages that can be obtained, and it is hoped this table will provide a worthwhile overall picture, from which it will be seen that broadly speaking five different types of engines were produced by the Wright Brothers over a period of nine years.

Apart from the first experimental engine, undoubtedly the most important was Type III, the 4-cylinder vertical, which really made flying history and was manufactured in several countries in quantity production.

Dealing with Type I, the original engine, with which mechanical flight was first achieved in December 1903, this was a flat, 4-cylinder, liquid-cooled, square engine of 4 in. bore by 4 in. stroke, of 3¼ litres capacity. It developed 16 horsepower momentarily, but owing to the design of

TABULATION OF THE WRIGHT BROTHERS' ENGINES

Type I	1903	Horizontal	4-cyl.— 4 in. × 4 in.	12 b.h.p. at 1,100 r.p.m.	14 lb. per b.h.p.	1st experimental
Type II	1905	Horizontal	4-cyl.— 4⅛ in. × 4 in.	18 b.h.p. at 1,350 r.p.m.	10 lb. per b.h.p.	Modified experimental
Type III	1908	Vertical	4-cyl.— 4⅛ in. × 4 in.	30 b.h.p. at 1,400 r.p.m.	6·7 lb. per b.h.p.	1st production series
Type IV	1910	V-8	8-cyl.— 4⅛ in. × 4 in.	55 b.h.p. at 1,400 r.p.m.	5·2 lb. per b.h.p.	Racing engine
Type V	1912	Vertical	6-cyl.— 4⅛ in. × 4½ in.	60 b.h.p. at 1,450 r.p.m.	5·0 lb. per b.h.p.	2nd production series

Figures are average maintained b.h.p.: dry weight without radiator and water, but with ignition.

the cast iron cylinder heads, which were uncooled, the best power that could be held for a few minutes was 12 b.h.p. at 1,090 r.p.m. The crankshaft was machined from a solid, 1·9 in. thick, sheet of armour plate. It ran in five Babbit-lined main bearings, and weighed 19 lb. when finished. The cylinders were individual castings in fine-grained cast iron, and these were fitted into a single-piece cast aluminium crankcase, the extensions of which formed a water-jacket round the barrels.

The crankcase was the most revolutionary bit of design, as aluminium in those days was a metal not far removed from titanium as a rarity today. The connecting rods were seamless carbon steel tubing, screwed into bronze big-ends. Pistons were fine-grained cast iron, and the valves had steel stems with cast iron heads. A camshaft driven from the crankshaft with an external chain operated the exhaust valves. The inlet valves were opened by natural aspiration. The whole internal lubrication system depended upon splash from strategically placed troughs and cups in the crankcase.

Ignition was supplied by a low tension horse-shoe generator, friction-driven from the external 15 in. diameter flywheel. It is interesting to note, however, that four dry-cell batteries and a home-made coil, which were not fitted on the aircraft and used only for starting, furnished a hot spark, and, combined with the geared propellers, undoubtedly, were mainly responsible for the consistently good starting which proved a great boon to the Wrights.

The fuel system consisted of the simplest form of direct fuel injection and was by gravity to a shallow enclosed and baffled pan, covering the four cylinders above their water-jackets. There were two valves in the fuel line for metering adjustments, and the only way to stop the engine was to close one of these valves, since there was no throttle. The two chain-driven propellers ran in opposite directions and rotated three times in relation to ten revolutions of the engine, an important factor in their success.

Some criticism has been made of the Wrights' twin chain-driven arrangement, and questions have been asked as to why they did not use a single propeller bolted direct to the flywheel. Here, again, the Wrights showed their great wisdom. Although this chain-driven solution was an extremely bold one, and gave them some considerable trouble to start with because of the sprockets coming loose, they eventually solved this problem, and from then onwards the scheme proved very satisfactory and was perpetuated on all their future types. The propeller efficiency was exceptionally good; they considered it was 65 per cent., no mean performance for a machine with a top speed of 35 miles per hour. The propellers were running out in the open in clean air, and provided an automatic spring drive as well as helping easy starting; and there is little doubt that if they had adopted a single propeller directly coupled to the engine, the aircraft would never have flown at all.

Type II was of exactly the same general layout as the first original engine. The bore was increased to 4⅛ in., a geared oil pump was added, and a compression release to further assist starting, stopping, and gliding was introduced. It will be seen, therefore, that in this original power plant conception, the Wright Brothers boldly tackled several basic problems that were to concern aero engine makers for some years to come.

By the Autumn of 1905, the Wrights had built up a thoroughly good knowledge of running these engines satisfactorily, and had a series of most successful flights, the longest of which lasted 38 minutes and was curtailed only by running out of fuel. It was this experience and familiarity with the engine which enabled them to build up a great deal of prestige and good will with their flying.

Type III was undoubtedly the most important and classic engine of the Wrights' series. The bore was increased to 4⅛ in. The cylinders were now vertical, but there was still no water-cooling to the heads. A high tension magneto was employed with conventional sparking plugs. The same type of direct fuel injection was employed, but a gear-driven petrol pump was added, driven by a skew gear from the camshaft, the pump having two spur gears about ⅛ in. thick. The camshaft, petrol pump and oil pump were now all gear-driven.

An intake manifold with internal baffling conducted the fuel mixture to each cylinder, fuel being introduced through a small jet orifice. The radiator system was somewhat heavy, but simple and robust, and had two sets of flat tubes soldered into header tanks. Brass tubing was used with rubber joints, and a centrifugal pump, driven (ingeniously by a pair of rotating arms to avoid misalignment troubles) from the front of the engine, was introduced. Speed control was by advancing the ignition.

This engine came into production in 1908, developing 30/32 horsepower, and by 1910 it was giving about 40 horsepower. It contributed very considerably to the remarkable flying displays of Wilbur in France and Orville in the U.S.A. during 1908, all of which created a tremendous impression as regards reliability, endurance, and controlled banked turns, and established the Wright Brothers' machines in the forefront, in spite of some keen competition.

The engines were fairly quickly dismountable and were supplied with a practical fan dynamometer in order to take power readings. This arrangement was similar to the Walker, which was well known at the time in Europe. During engine acceptance tests the exhaust flame was carefully noted. Occasionally the time required to consume one gallon of gasoline was checked, and some engines were run as much as 16 hours before they were satisfied they were suitable for delivery.

A description in the Papers of how the Wrights calibrated this fan dynamometer from their gas engine, which was used to drive the plant at their Dayton Works, is extremely interesting and practical, and demonstrates their thorough grasp of the power plant problem.

Type III was made in series production under license in several countries. The first batch of Short aircraft had their engines supplied by France, and the Wright Brothers were harassed by some of the stupid and dangerous things that were done by quite well known firms which had undertaken the manufacture of these engines. This illustrates the great wisdom shown in later days by the meticulous manufacturing and inspection technique laid down by the A.I.D. for the manufacture of aero engines. Exhaust valve breakage was an early trouble on these production engines, and to alleviate this, elongated holes were employed near the base of the cylinders. Eventually the exhaust valve trouble was cured after trying about 150 modifications to the camshaft contours. This valve trouble worried the Wright Brothers so much, that while it was in process of being cured they embarked upon the desperate measure of designing, making, and actually running a 4 cylinder rotary-valve engine, but this was soon abandoned.

Type IV was a V-8 special racing engine, duplicating the cylinders of Type III. It was highly experimental and only flown a few times. Orville Wright put up a good performance with it at Belmont Park in 1910 at nearly 80 m.p.h. It was crashed at take-off in the Gordon Bennett Race immediately afterwards, and from then onwards the engine was abandoned. Only two engines were built.

Type V was a vertical 6-cylinder engine produced in 1912, and was the last engine designed by the Wrights. It was a logical development of the Type III, but had a number of modifications, including water-cooled cylinder heads and mechanically-operated inlet valves. A manually-operated valve release rod opened all valves simultaneously for gliding without power. Twin Zenith carburettors were employed.

A bench test of this engine taken at Farnborough in January 1915 recorded 69·5 b.h.p. at 1,450 r.p.m., and on an endurance test of 4¾ hours, the fuel consumption was 0·716 pints per b.h.p. per hour and the oil consumption 0·0384 pints per b.h.p. per hour.

This engine was in constant use in the U.S.A. in the early days of the 1914/18 War for training purposes, before America came into the War.

Such were the practical and realistic solutions the Wright Brothers used for their power plant, and without any special materials, intensive knowledge, or development work on thermodynamics, they produced two successful production types which employed a number of intelligent and original ideas. Taking fully into consideration their lack of opportunity to study engine technique, and the comparatively primitive methods of manufacture and general absence of high quality materials, the results they obtained were outstanding.

ADHESIVE BONDING OF METALS. *George Epstein. Reinhold Publishing Corporation, New York, 1954. 218 pp. Illustrated. 24s.*

The author of *Adhesive Bonding of Metals* is a research engineer with North American Aviation, so it is not surprising that in his book, which is partly a treatise and partly a manual, the emphasis is on the use of adhesives in aircraft.

Mr. Epstein starts off by making out a strong case for gluing metal and in this he is supported by the deficiencies inherent in other methods of joining metal, particularly of thin gauges. He goes on to describe some typical metal adhesives, including some which have specially good high-temperature strength. There is a chapter on the design and testing of glued joints, another on gluing techniques and the last chapter deals with adhesives for metal sandwich constructions. There is an informative section on rubber-to-metal bonding.

In discussing the polyurethanes, the author says these have not yet come up to government requirements for structural adhesives—a statement which may surprise some readers who have not followed this development closely but who recall the claims made for the polyurethane adhesives by Germany at the end of the war.

Mr. Epstein gives information about a high temperature adhesive he has developed: the strength of this at 500° F. is good, but at room temperature it is not in the class of really high-strength adhesives. It is unfortunate that details such as, for example, gauge of metal and proof stress, which must be given in order to obtain a proper appreciation of joint strength, are frequently omitted; another important omission is the rate of loading.

In dealing with the design and testing of glued joints it is interesting to see that the author considers the American bend test to give a better indication of flexibility of the adhesive than the peeling test—but he does not tell us why.

The chapter on sandwich constructions contains some brief details of inspection test methods. As the author points out, in the making of sandwich constructions, adhesives have everything their own way.

Because the gluing of metals is arousing more and more interest and because little literature on the subject is available, there is room for Mr. Epstein's book. Engineers and technicians—for whom the book is primarily written—will find in it much useful information.—C. A. A. RAYNER.

PROCEEDINGS OF THE THIRD MIDWESTERN CONFERENCE ON FLUID MECHANICS. *Published by the University of Minnesota, 1953. 783 pp. Diagrams. 51s.*

This volume contains all of the paper presented at the Third Midwestern Conference on Fluid Mechanics held at the University of Minnesota from the 23rd to the 25th of March 1953. The Conference consisted of two parts, both of which were confined to work done in the U.S.A. The first part was sponsored by the Office of Ordnance Research and was devoted to transport phenomena; it included six papers on subjects ranging from heat transfer at supersonic speeds to the transportation of sedimentation. The second part was sponsored by the American Physical Society and by the local branches of several other societies. It contained thirty-six papers dealing with a wide range of topics relevant to fluid motion at both low and high speeds. There were twelve papers on inviscid and quasi-inviscid flow, three on turbulence, nine on experimental methods, eight on boundary layers and four on temperature effect and combustion. The number of papers is so large that it is not possible to give details of the individual papers in a short review. The majority of them describe investigations of fundamental matters, and many will be of interest to those concerned with the aerodynamics of aircraft, missiles and gas turbines, and with the design and operation of wind tunnels.

Although there are contributions from several government and industrial laboratories, most of the papers originated at universities. This illustrates the very large amount of research on fluid mechanics that is in progress at American universities, much of it under contract from the government or the industry. Over two hundred people attended the Conference and, although no details are given in the proceedings of the discussions that followed the presentation of the papers, there can be little doubt that these were of considerable value to those present. Conferences of this type must be particularly desirable in the U.S.A. where the great distances that separate individual workers may make it difficult for them to meet otherwise. Although these difficulties are not so acute in the United Kingdom, it is possible that similar conferences would serve a useful purpose in bringing together those engaged in research on different aspects of fluid mechanics.

The volume contains numerous photographs and diagrams and is excellently reproduced. All who are interested in fluid mechanics will wish to see it, but in view of the price it is doubtful whether many will buy copies for personal use.—D. W. HOLDER.

JANE'S ALL THE WORLD'S AIRCRAFT 1954-1955. *Edited by Leonard Bridgman. Jane's All The World's Aircraft Publishing Co. Ltd., London, 1954. 379 pp. Illustrated. £4 4s. 0d.*

The beauty of reviewing for a monthly Journal is that one can read everything that the dailies and weeklies say and then mix a little of them all. Unfortunately, with a book like Jane's, everybody says practically the same and it simply means—Jane's is available again, the price is the same as last year, the standard is as high as it always has been and there is still nothing like it. What this reviewer has been wondering for some time is, how would the Editor "get round" that flying bedstead—Engines or Aircraft? Rather craftily he has put it in the Preface, which will provide a nice riddle for Posterity.—F.H.S.

GAS DYNAMICS OF THIN BODIES. *F. I. Frankl and E. A. Karpovich. Translated from the Russian by M. D. Friedman. Interscience Publishers, London and New York, 1954. 175 pp. 33 diagrams. 38s.*

Bearing in mind the difficulty in finding and interpreting Russian technical literature, a translation such as this is bound to have a particular interest. It was originally published in 1948, and it is surprising to find that theoretical research was developing along such similar lines on both sides of the Iron Curtain at this time. Thus, what we know as Evvard's treatment of the supersonic flow over wings appears here as the work of Mme. Krasilshchikova; their derivations of what is, after all, quite a subtle method appear to be identical, simultaneous and independent. One can discover many examples of such duplication when reading the book, and indeed the translator—who should, by the way, be congratulated—is constrained to describe the opening pages as "a supra-nationalistic section glorifying the achievements of Soviet mathematicians." However, in all conscience, one must admit that such partiality in awarding "credits" is not uncommon in technical literature.

One gains, nevertheless, not merely a knowledge of the extent of the Russian literature from this book. It also happens to be an excellent account of its subject. Certain theoretical advances have been made since the book was written, so that it is easy now to suggest improvements: but the treatment given is well-reasoned and clear. The accent throughout is on the steps of the mathematics, rather than the physical implications of the results—beyond a brief reference, where appropriate, to their accuracy (framed with commendable conservatism). So far as the reviewer may discern, no important errors, and only one or two misprints, exist in the text—except in the analysis of the flow about a double-cone (p. 35).

The subject matter is restricted to a few well-chosen topics, which allows attention to be focused on details in the mathematical techniques. The potential of a source moving arbitrarily in a compressible gas is first derived, and forms the basis upon which the authors build up (in their second chapter) the theory of flow about slender bodies of revolution. Chapter III contains a brief account of two-dimensional aerofoil theory, and of (subsonic) lifting line theory, but it is mostly taken up with the details of Mme. Krasilshchikova's method. The next chapter outlines Khaskind's analysis of the subsonic flow about an oscillating wing, and the corresponding problem in supersonic flow is neatly assailed using distributions of "pulsating" sources; the chapter ends with a general account of the vortex theory of propellers in a compressible gas, which is of particular value. Finally the methods of conical flows are discussed, including generalisations applicable to slightly curved wings, and bodies without axial symmetry.

The book is clearly printed and adequately illustrated.—T. NONWEILER.

AIRPLANE STRUCTURES. *Volume I. A. S. Niles and J. S. Newell. Fourth Edition. John Wiley, New York, and Chapman & Hall, London, 1954. 607 pp. Diagrams. Index. 62s. net.*

Readers who are familiar with the third and previous editions of this well known textbook on aircraft structures may well fail to recognise this fourth edition. Parts of the original material have been severely pruned while other parts have been expanded and rearranged. The progress made in aeronautical structures, since the previous edition in 1943, has occasioned this revision, which, Professor Niles informs us in his preface, had been all but completed at the time of Professor Newell's death in 1952.

Many changes which have been made in deference to progress are relatively unimportant; as for instance the substitution of a modern jet outline for that of a parasol monoplane which was used in the first figure to illustrate the forces on an aeroplane in flight. Other changes have a more serious reflection on the progress made during the past few years. Much of the material which dealt with wooden structures has been removed and replaced so as to give a more complete coverage of thin metal construction. Allied topics, such as gusts and fatigue, are now honoured with complete sections whereas in the earlier editions they received only a passing mention. The treatment of compression structure has been brought up to date and the analysis of tension field beams is now based on the most recent work as contained in N.A.C.A. Technical Note 2661. Apart from expanding the information contained in the earlier editions a complete new chapter has been added on properties of structural materials. The analysis of statically indeterminate structures has been brought forward from the second volume of the work. Also noteworthy is the revised chapter on connections, much of which, in the earlier editions, appertained to wooden and welded steel tube structures.

As noted, those familiar with the earlier editions may well fail to recognise this book as the old and trusted friend. Responsibility for this rests on the type face used in the fourth edition, for it has neither the boldness nor character

of that used previously. Apart from this the presentation is neat and in every way adequate.

Airplane Structures was always noteworthy in that it based a part of its content upon the official publications of the United States Government Agencies and this is still very much in evidence. Useful material is reproduced from N.A.C.A. Technical Reports and Notes and the well known bulletin ANC-5 of the Munitions Board Aircraft Committee. This feature enhances the value of the book as a work of reference as well as of instruction and, in this respect, the authors are further to be congratulated on including a large number of references on specific problems.

Some readers might ask why, in a book which has just been revised to include recent advances in structural engineering, no mention has been made of work on structural efficiency; they may well feel that it is never too early to impress upon the student that a structure must be efficient as well as sufficient in its purpose. Others may be of the opinion that the subject of structural efficiency is too complex and controversial at the present time to warrant even the briefest consideration in a book written primarily for undergraduates. Whatever the outcome of this argument might be, the reviewer feels that this latest edition will maintain "Niles and Newell" as one of the foremost textbooks in the preparation of undergraduate students in American Universities and, in the absence of a comparable modern British textbook, will continue its use by many students in this country.—A. J. BARRETT.

ALL ABOUT AIRCRAFT. *D. M. Desoutter. Faber & Faber, London, 1954. 474 pp. Illustrated. 25s.*

"A.A.A. is designed," says the publisher, "to provide the layman with a compendium of sound aeronautical information, in the light of which he will be equipped to understand the daily news of aviation's advances." This formidable task has been tackled by the author with considerable success. The first part of the book describes the aeroplane's aerodynamics, structure, propulsion, and equipment and includes essays on the history of human flight, on records, careers and research in aviation. Then there are over one hundred photographs and drawings of representative modern aeroplanes (including even a photograph of the R.R. "flying bedstead" and a three view G.A. of the English Electric P.1).

The essence of these complicated subjects has been compressed into a few pages but there is no reason for the experts to be disappointed at the result: the author writes easily but without hint of condescension. Many sketches help the verbal descriptions, numbers are given in diagrams and tables whenever possible and equations occur but rarely. The reader who expects to find the author plugging the metric system of measurement may be surprised to find that speeds are almost all in ml./hr. The word "knot" has been excluded even from the glossary.

The format of the book is unusual, each page being only 5 in. high and 7½ in. wide. The book remains easy to read but its aspect ratio makes it difficult to fit into a bookshelf. The quality of the paper and printing is high.

The student, the technician, the company director, the Member of Parliament who has at hand a library of up-to-date textbooks on all branches of aeronautics and a complete set of aeronautical reference books can dispense with this book. If these books are not at hand, Mr. Desoutter's compendium will replace them on very many occasions.—A. H. YATES.

THE OBSERVER'S BOOK OF AIRCRAFT. *(1955 Edition.) William Green and Gerald Pollinger. Frederick Warne, London and New York, 1954. 287 pp. 309 illustrations. 5s.*

On the back of the title page of this book will be found a list of the editions, impressions and what have you that it has "run into." There are so many impressions, revised impressions to the first, second and third place that it is all rather difficult to follow but the fact that the one under review is the ninth in two years bears fairly eloquent testimony to this poor man's cum small boy's "Janes." In testing the up-to-dateness of such a book, one thinks of something that has hit the headlines in the past month or two. English Electric P.1A? It is there as far as publication is allowed. The system of putting all aircraft in alphabetical order of manufacturer and not subdividing into country of origin almost makes an index redundant but on the other hand, if you want to know where, for instance, to find the Retriever you will find it under that in the Index which will lead you to the Piasecki entry in the body of the book. The reviewer cannot compare this with the last edition as the Library copy has disappeared. It certainly is a most useful book and so handy for the pocket.—F.H.S.

Additions to the Library

Abbott, W. MACHINE DRAWING AND DESIGN. Blackie. 1954.

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Bridgman, L. (*Compiler and Editor*). JANE'S ALL THE WORLD'S AIRCRAFT, 1954-55. Jane's All the World's Aircraft Publishing Co. Ltd. 1954.

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Knowler, A. E. and D. W. Holder. THE EFFICIENCY OF HIGH-SPEED WIND TUNNELS OF THE INDUCTION TYPE. A.R.C. Monograph. H.M.S.O. 1954.

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Swainger, K. ANALYSIS OF DEFORMATION, VOL. II (EXPERIMENT AND APPLIED THEORY.) Chapman & Hall. 1954.

von Mises, R. STUDIES IN MATHEMATICS AND MECHANICS (PRESENTED TO). Academic Press. 1954.

Reports

AERODYNAMICS

Rolling characteristics of narrow-delta cruciform wings with canard-delta or trailing-edge ailerons. K. Walker. Douglas Report No. SM-18309 (March 1954).

The roll characteristics of narrow-delta cruciform wings with trailing-edge or canard-delta ailerons are investigated using linearised supersonic wing theory. Equations and graphs for rolling moment derivatives are presented as functions of Mach number and wing and aileron geometry.—(1.3.1).

Les fonctions et intégrales elliptiques a module réel en mécanique des fluides. R. Legendre. O.N.E.R.A. France. Publication No. 71 (April 1954).—(1.4.1 × 22.1).

The jettisoning of liquids from an airplane in flight. F. R. Riddell. Douglas Report No. SM-18279 (March 1954).

Some brief calculations to show the main physical features of the problem of how to jettison fluids from an aeroplane in flight so as to avoid contamination of the aft section are given. On the basis of the picture thus formed a rational approach to nozzle design is presented. The results of some simple experiments and a general discussion of the difficulties in adequate model testing are included.—(1.4.2).

Low speed tests on three aerofoil cascades designed for prescribed surface velocity distributions. P. V. Crooks and W. Howard. A.R.L. Australia. Report ME.76 (June 1954).

The performance of three new blade shapes designed by the exact Lighthill method to have prescribed velocity distributions has been measured and compared with that of a conventional compressor aerofoil in cascade. The tests were performed at chord Reynolds numbers near 2×10^5.—(1.5.4.2).

The design of power plant ducting. H. S. Fowler. N.R.C. Canada. Report No. ME-208 (May 1954).

The aerodynamic design of power-plant ducting is considered, covering both pipework and the passages in cast components. The remarks apply to all gases, and qualitatively also to liquid flow. The design aim is to minimise pressure loss, to obtain uniform flow distribution, and to produce a form mechanically suited to the machinery.—(1.5.1.1).

Lift developed on unrestrained rectangular wings entering gusts at subsonic and supersonic speeds. H. Lomax. N.A.C.A. Report 1162 (1954).

Lift forces induced by a vertical gust on wings of rectangular plan form are estimated on the basis of theoretical calculations. The effects of Mach number (from 0 to 2) and aspect ratio (2 to ∞) are included, and solutions are given by means of which the response to gusts having arbitrary streamwise gradients can be calculated. Results are presented for sharp-edged and triangular gusts and various wing-air density ratios.—(1.6.3).

Calculated subsonic span loads and resulting stability derivatives of unswept and 45° sweptback tail surfaces in sideslip and in steady roll. M. J. Queijo and D. R. Riley. N.A.C.A. Technical Note 3245 (October 1954).

Subsonic span loads have been calculated for a systematic series of unswept and 45° swept-back tail surfaces by the discrete-horseshoe-vortex method. Results are presented as charts of span loads and the resulting contribution to the side-force and rolling derivatives. Geometric variables covered in the investigation included vertical- and horizontal-tail aspect ratios and vertical position and dihedral of the horizontal tail for various tail assemblies in sideslip and steady roll. Also presented is an extensive table of values of sidewash due to a rectangular vortex.—(1.8.1.2 × 1.6.2).

The wave drag of highly swept wings; a comparison of linear theory and slender body theory. T. Nonweiler. College of Aeronautics Note No. 14 (October 1954).

The answer obtained by linear theory for the wave drag of slender-wings (as interpreted by the limit $(M^2-1)^{\frac{1}{2}} \cot \Lambda \to 0$) is compared with that value for the drag obtained by slender-body theory. Some remarks are included concerning the drag of slender delta wings.—(1.10.1.2).

Influence de la position du maitre-couple sur les ecoulements transsoniques autour de profils a pointes. R. Michel, F. Marchaud and J. Le Gallo. O.N.E.R.A. France. Publication No. 72 (March 1954).—(1.10.2.1).

Considerations on the effect of wind-tunnel walls on oscillating air forces for two-dimensional subsonic compressible flow. H. L. Runyan and C. E. Watkins. N.A.C.A. Report 1150 (1954).

The wind-tunnel walls are simulated by the usual method of placing images at appropriate distances above and below the wing. An important result shown is that, for certain conditions of wing frequency, tunnel height, and Mach number, the tunnel and wing may form a resonant system so that the forces on the wing are greatly changed from the condition of no tunnel walls.—(1.12.1.1).

AEROELASTICITY

See also STRUCTURES

Lift and moment equations for oscillating airfoils in an infinite unstaggered cascade. A. Mendelson and R. W. Carroll. N.A.C.A. Technical Note 3263 (October 1954).

Aerodynamic coefficients similar to those of the isolated aerofoil are obtained as functions of the cascade geometry and the phasing between successive blades; the phasings considered are zero, 90°, and 180°. These aerodynamic coefficients are plotted for the special case when all the aerofoils are vibrating in bending in phase (360° phasing). It is shown that the effect of cascading for this case is to reduce greatly the aerodynamic damping.—(2.0 × 1.5.4.1).

AIRPORTS

Evaluation by simulation techniques of a proposed traffic control procedure for the New York metropolitan area. Clair M. Anderson and C. E. Dowling. C.A.A. Technical Development Report No. 245 (August 1954).

This report describes a study to determine methods of expediting air traffic to and from the six major airports in the New York metropolitan air-traffic-control area. This study was made with the aid of simulation techniques developed jointly by the Franklin Institute Laboratories for Research and Development and by the Technical Development and Evaluation Centre of the Civil Aeronautics Administration.—(6.5).

ELECTRONICS

Development of a variable-parameter DME interrogator. R. C. Borden, R. E. Carlson, J. R. Hoffman and H. G. McMurtrey. C.A.A. Technical Development Report No. 246 (September 1954).

This report describes the development of a test unit designed to permit airborne checking of the performance, coverage, system interference, and multipath transmission of the DME transponder.—(11).

HYDRODYNAMICS

The hydrodynamic characteristics of an aspect-ratio-0·125 modified rectangular flat plate operating near a free water surface. J. A. Ramsen and V. L. Vaughan. N.A.C.A. Technical Note 3249 (October 1954).

Results of an investigation of the hydrodynamic force characteristics of an aspect-ratio-0·125 modified flat plate on a single strut operating near a free water surface are presented. Comparisons are made between these data and similar data from previous tests on plates having aspect ratios of 1·00 and 0·25. The experimental effects of varying the depth of submersion and angle of attack are shown. The effects of cavitation at the leading edge and of the

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

planing-bubble type of high-angle separation are presented. Comparisons are also presented between the experimental lift for all three aspect ratios at large depths of submersion and several theoretical methods of predicting the lift.—(17.1).

INSTRUMENTS AND EQUIPMENT

C.A.A. Type II automatic flight and navigation equipment. J. W. Watt and L. E. Setzer. C.A.A. Technical Development Report No. 247 (*September* 1954).

This report discusses the operation of the C.A.A. Type II Automatic Flight and Navigation Equipment and describes some of the circuits which were combined in it. Basically, the equipment is an airborne course-line computer which operates upon data from a self-contained storage unit and from omnibearing-distance (O.B.D.) information to produce left-right guidance along a selected course and to provide aeroplane-to-waypoint-plane-distance indications. — (18.1 × 26.0).

Development of helicopter blade tip lighting. M. J. Anderson and C. B. Phillips. C.A.A. Technical Development Report No. 248 (*October* 1954).

Special high-intensity lighting units for helicopters were developed to be housed in the blade tips, which were modified to accommodate the units and to include clear plastic windows. The mass dynamics and the aerodynamic contours of the tips were unchanged.—(18.1).

MATERIALS

Early hardness changes on ageing aluminium-copper alloys. L. M. Bland. A.R.L. Australia. Report Met. 4 (*June* 1954).

Age-hardening curves are determined for the early stages of ageing of a 4 copper aluminium-alloy at temperatures between 0 and 200°C; and a modification of the first part of the general age-hardening curve proposed by Hardy for the aluminium-copper alloys is suggested. Microscopic examination and microhardness surveys of polycrystalline specimens, and hardness tests on single crystals show that the early hardness changes are not associated with localised precipitation. It is suggested that the early age-hardening may be associated with composition fluctuations formed in the system at a higher temperature and retained as stable groupings by the quench.—(21.1 × 21.2.2).

The growth of fatigue cracks. A. K. Head. A.R.L. Australia. Report Met. 5 (*July* 1954).

Most theories of fatigue assume that the major part of the fatigue life is completed before the formation of a crack which, once formed, grows rapidly causing fracture. However there is a small amount of evidence that the crack is formed in the early stages and then grows slowly for a large number of cycles. A model of a fatigue crack is proposed and its rate of growth is found to be in satisfactory agreement with measurements of the growth of fatigue cracks.—(21.1 × 21.2).

Les matériaux cellulaires a base de polyesters et diisocyanates. J. Grosmangin and C. Muller. O.N.E.R.A. France. Note Technique No. 22 (1954).—(21.3.3).

An experimental and theoretical investigation of the anisotropy of 3S aluminum-alloy sheet in the plastic range. A. J. McEvily and P. J. Hughes. N.A.C.A. Technical Note 3248 (*October* 1954).

The results of tension and compression tests on 3S aluminium-alloy sheet are presented together with values of Poisson's ratio in the plastic range. X-ray diffraction studies of annealed specimens were made and pole figures showing the type of preferred orientation were drawn. A theoretical analysis was made to account for the observed anisotropy based on the behaviour of single crystals and the texture of the sheet.—(21.2.2).

MATHEMATICS

See also AERODYNAMICS AND STRUCTURES

Les opérations arithmétiques en calcul binaire. J. Bouzitat. O.N.E.R.A. France. Note Technique No. 21 (1954).—(22.1).

POWER PLANTS

Assessment of the relative performance of the by-pass engine and the orthodox double compound jet engine. E. A. Bridle, R. & M. 2862 (*July* 1948, *published* 1954).

The by-pass engine can be described as a form of ducted fan engine in which the fan boosts the main compressor. Two possible forms of by-pass engine are described, and their estimated performance is compared with that of the orthodox double compound jet engine under various flight conditions, the calculations being extended to include the case of thrust boosting by means of exhaust reheat.—(27.1).

*Design, performance and analysis of ducted axial flow fans. R. A. Wallis. A.R.L. Australia. Report A.*88 (*August* 1954).

A method of designing ducted axial flow fans is presented for the case of a fan rotor with prerotators upstream and straighteners downstream. The design equations so obtained are applicable to any stator-rotor combination and can also be used for contra-rotating fans. A rapid estimate of the characteristic curve can be obtained from the general method of analysis given.—(27.1).

STRUCTURES

Extension of the statistical approach to buffeting and gust response of wings of finite span. H. W. Liepmann. Douglas Report No. 15172 (*February* 1954).

The response of a wing of finite span moving in a turbulent field is discussed. On the basis of thin wing theory and using concepts from the theory of homogeneous turbulence the mean square lift can be expressed in terms of a generalised aerodynamic admittance and one component of the power spectrum tensor of turbulence. Explicit results are given for several limiting cases.—(33.1.1 × 2).

Experiments on tail-wheel shimmy. O. Dietz and R. Harling. N.A.C.A. Technical Memorandum 1376 (*October* 1954).

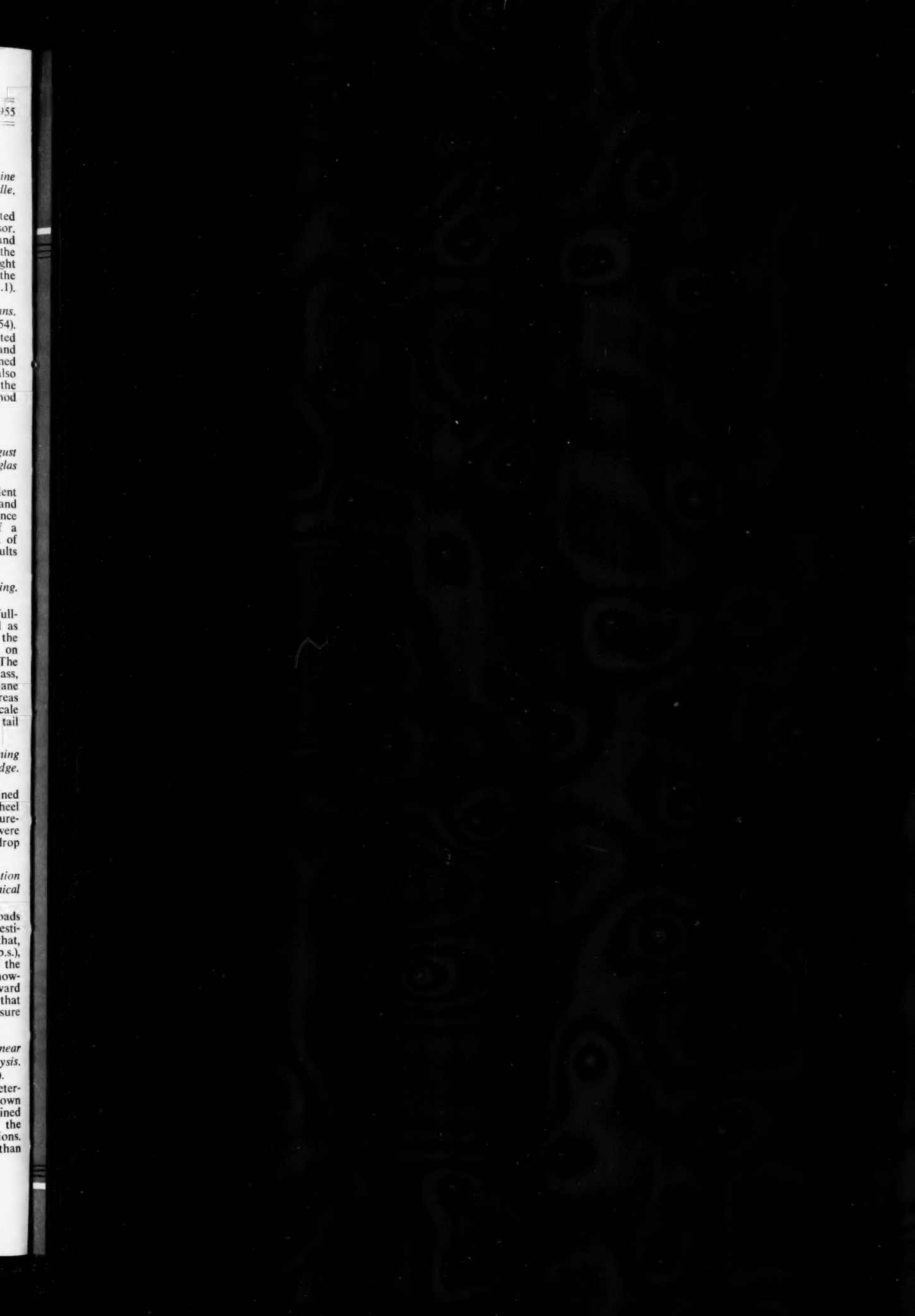
Model tests on the "running belt" and tests with a full-scale tail wheel were made on a rotating drum as well as on a runway in order to investigate the causes of the undesirable shimmy phenomena frequently occurring on aeroplane tail wheels, and the means of avoiding them. The small model (scale 1:10) permitted simulation of the mass, moments of inertia, and fuselage stiffnesses of the aeroplane and determination of their influence on the shimmy, whereas by means of the larger model with pneumatic tyres (scale 1:2) more accurate investigations were made on the tail wheel itself.—(33.1.2).

An evaluation of an accelerometer method for obtaining landing-gear drag loads. J. G. Theisen and P. M. Edge. N.A.C.A. Technical Note 3247 (*October* 1954).

An evaluation is made of applied ground drag loads obtained by means of angular-acceleration measurements on the wheel of a landing gear together with vertical-acceleration measurements on the upper and lower masses. The data were obtained during forward-speed landing impacts and drop tests in the Langley impact basin.—(33.1.2).

An experimental investigation of the effect of wheel pre-rotation on landing-gear drag loads. D. M. Potter. N.A.C.A. Technical Note 3250 (*October* 1954).

The effect of pre-rotation on the wheel spin-up drag loads on a small landing gear during landings has been investigated in the Langley impact basin. The results showed that, at the forward speed of the test (approximately 85 f.p.s.), even partial pre-rotation resulted in a reduction in both the drag load and the vertical load. At very high speeds, however, consideration of the variation of drag load with forward speed as obtained in a previous investigation indicated that large amounts of pre-rotation must be used in order to assure a reduction in drag load.—(33.1.2).

*Note on minimizing a quadratic function with additional linear conditions by matrix methods, with application to stress analysis. J. P. Benthem. N.L.L. Holland. Report S.*437 (*July* 1954).

The complementary energy of an n fold statically indeterminate structure is expressed as a function of m unknown generalised forces ($m>n$). The m forces are determined that minimise the complementary energy subject to the condition that these forces satisfy m-n equilibrium equations. The method leads to matrices of lower order to invert than the use of Lagrangian multipliers.—(33.2.1 × 22.1).